4D Modeling: Past, Present, and Future

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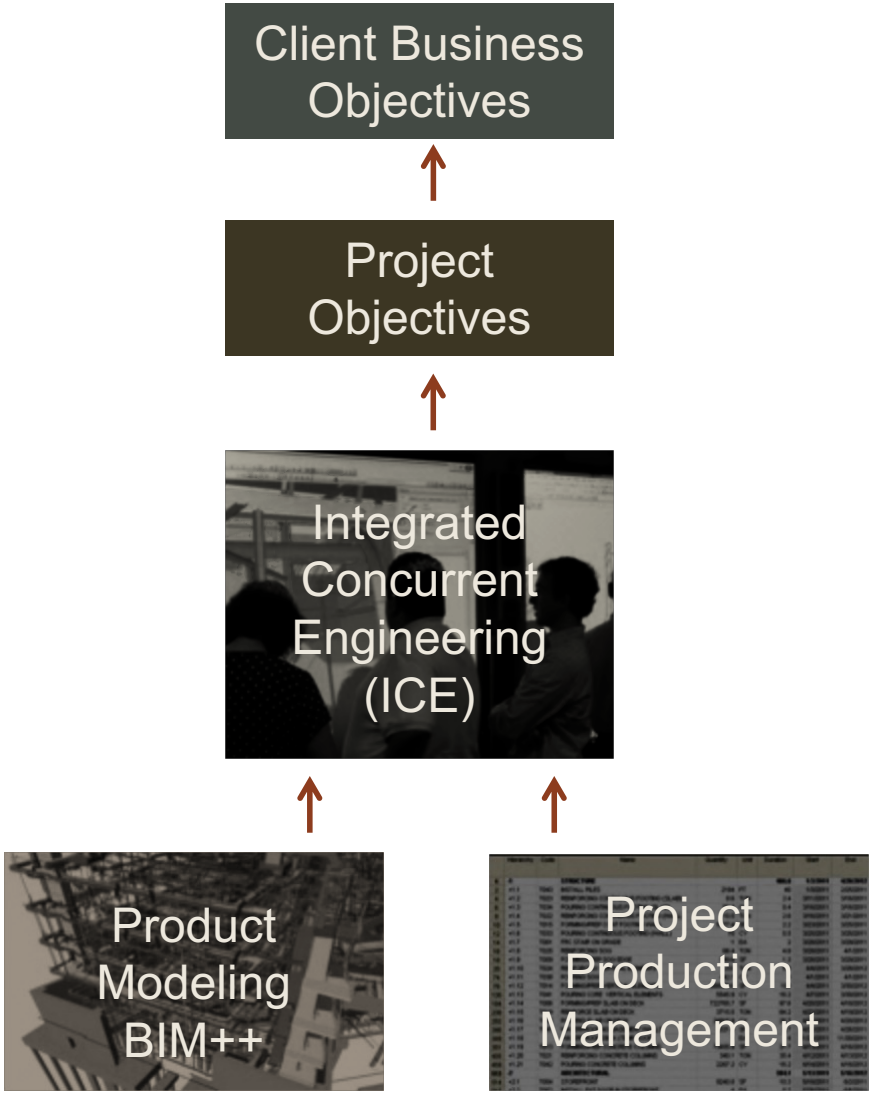
- Director, CIFE (Center for Integrated Facility Engineering)
- Foreign Member, Royal Swedish Academy of Engineering Sciences

CIFE

- 100% funded by industry
  - Building owners
  - Design and construction companies
  - Software and hardware vendors
- 1988-2000
  - Building Information Modeling (BIM)
- 2000-2010
  - Virtual Design and Construction (VDC)
- 2010+
  - Optimize Facility Performance

VDC Overview



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Why is 4D modeling fundamentally important for construction?

- The construction industry
  - gets paid for delivering a product (building, bridge, etc.)
  - delivers its products through applying work processes

- 4D = t + 3D or process + product or cost + value

- Time is what makes construction (and life …) “interesting”

- 5D, 6D, nD, xD, ...

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Outline

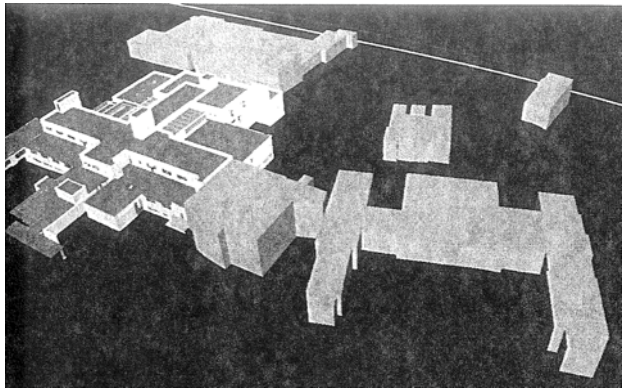
- Early 4D examples
- Back to the future
  - Easy interfaces
  - Rapid PDSA cycles
  - Parametric 4D modeling
  - Fabrication + construction
  - Metrics about the schedule
- What's next?
  - Beyond construction, multiple schedules
  - Automated 4D modeling
  - Data analytics
  - Metrics about the scheduling process

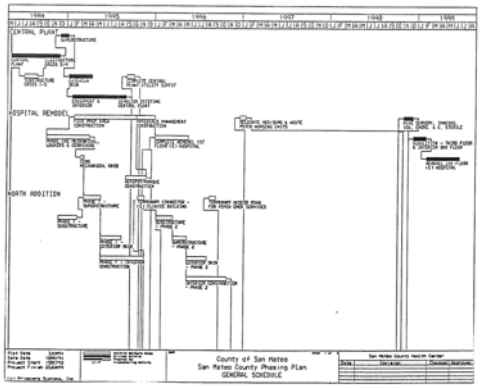
How I got into 4D modeling

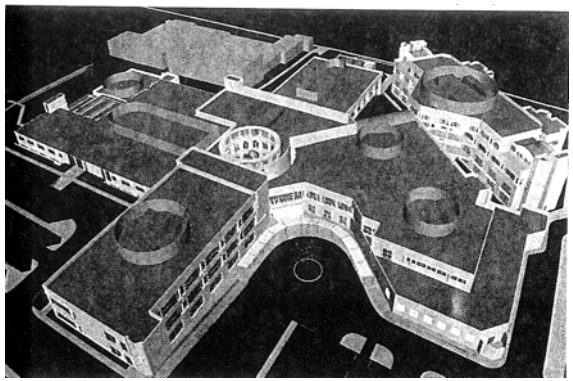
1986: Jamestown Verrazano Bridge, RI
VSL

1987: Buddy Cleveland, R&D, Bechtel
Construction Simulation Toolkit

1993: San Mateo County Health Center
Jack Ritter and George Hurley, Dillingham Construction







https://cife.stanford.edu/sites/default/files/TR101.pdf

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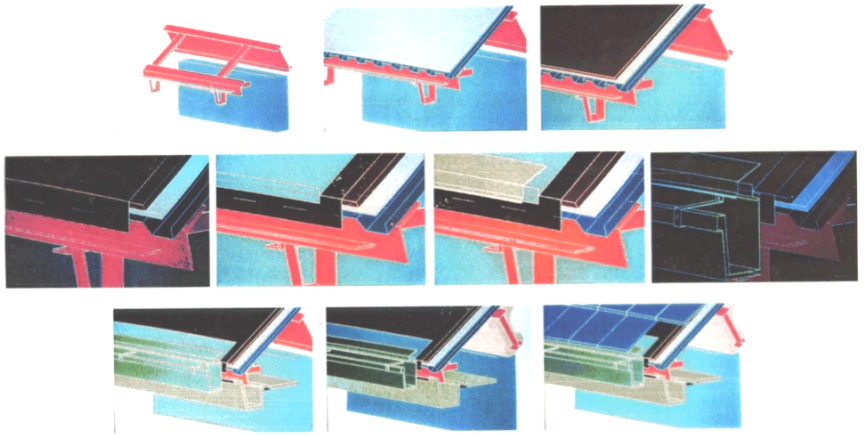
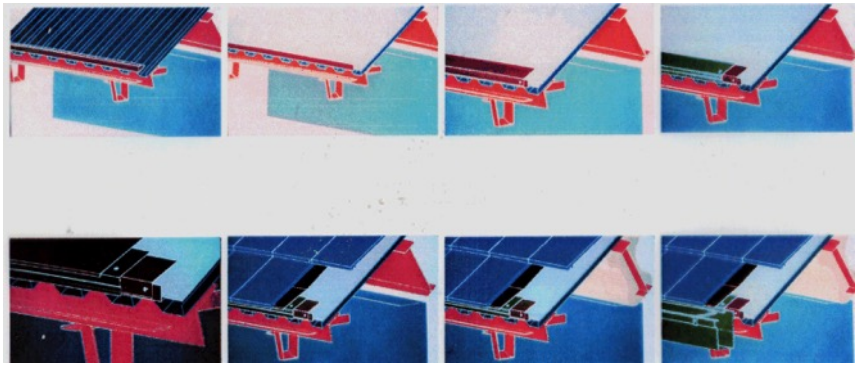
Very interesting … but my projects are not this complicated





1994 Collaboration with Todd Zabelle, Pacific Contractors

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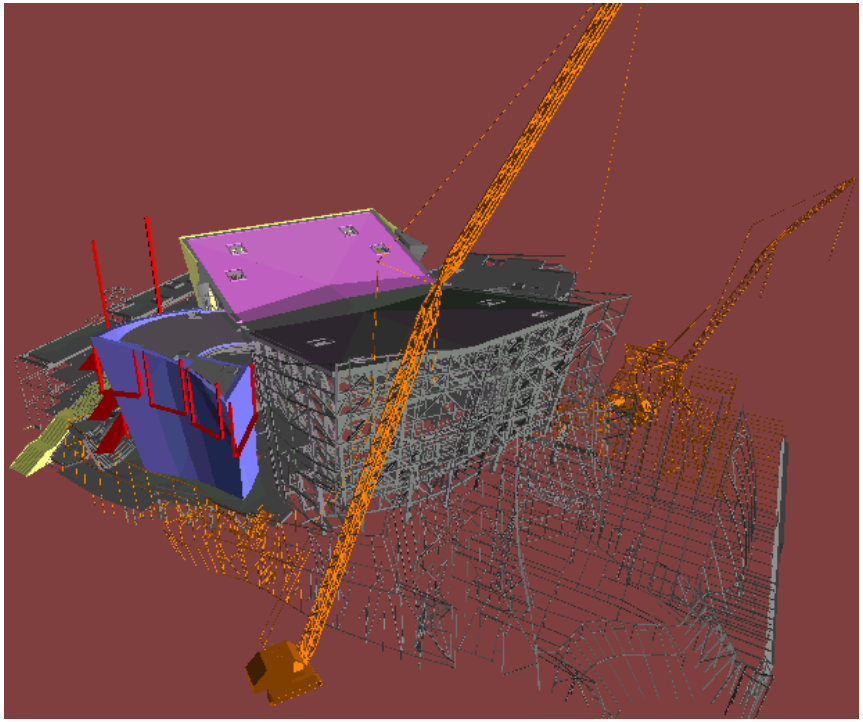
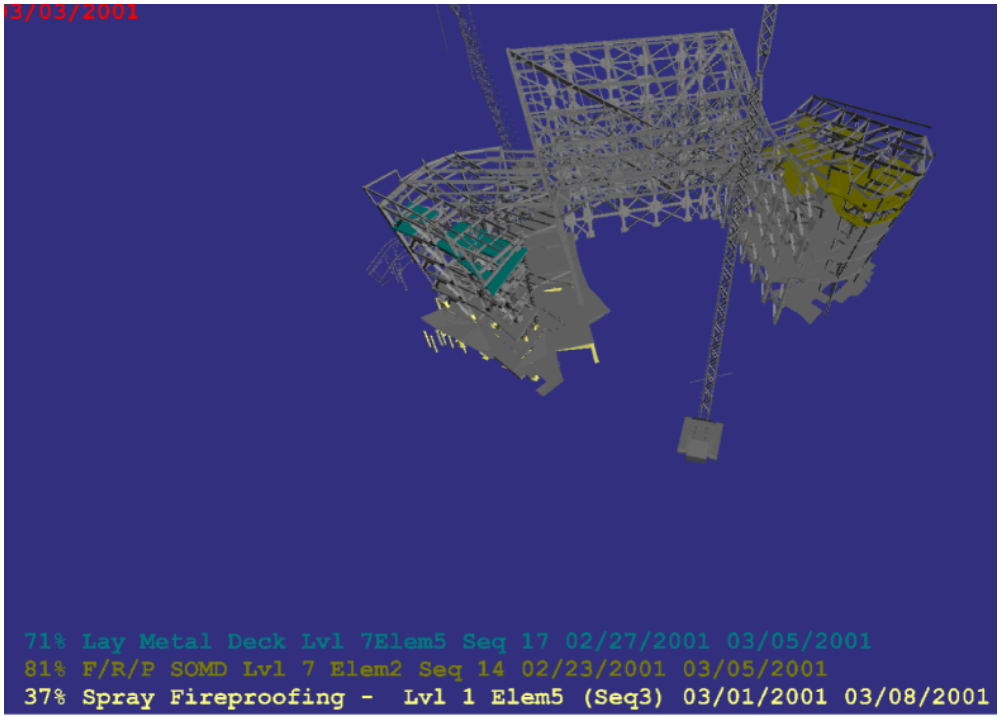
Develop and follow the construction strategy together with your subcontractors





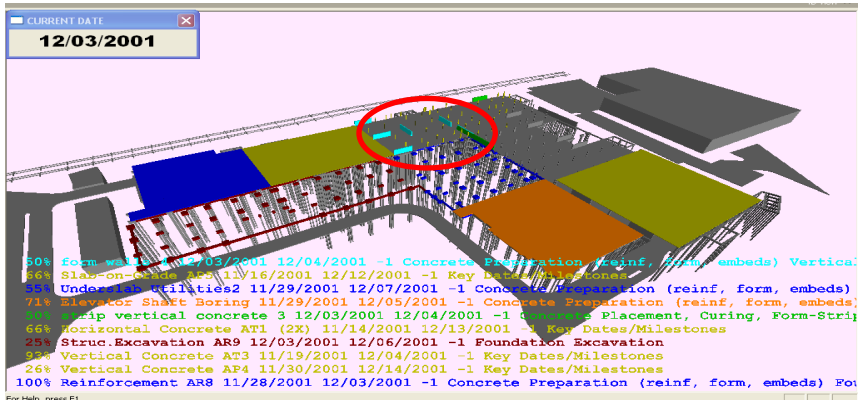
Courtesy Mortenson, Minneapolis, MN

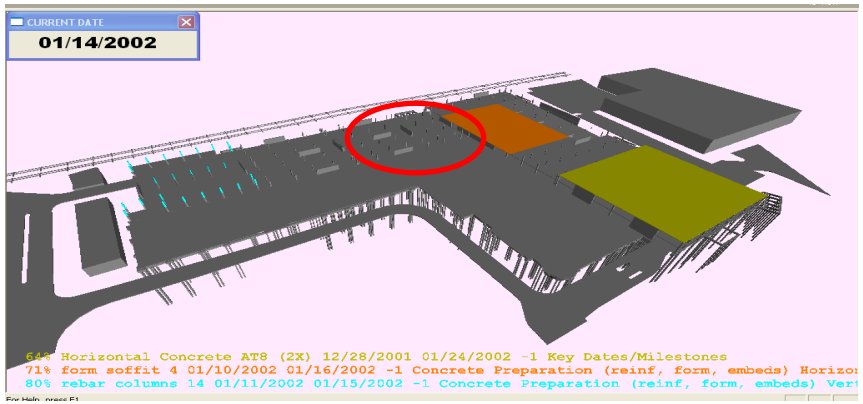
https://vimeo.com/7478800

Disney Project Manager:
“The problems we find together we solve together.”

Work with John Haymaker and Mortenson

4D models help see open spaces where work can be scheduled





Project example courtesy DPR and Common Point

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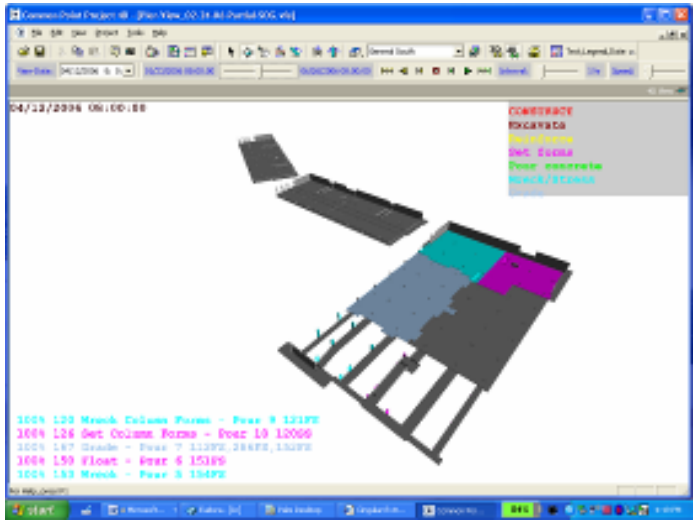
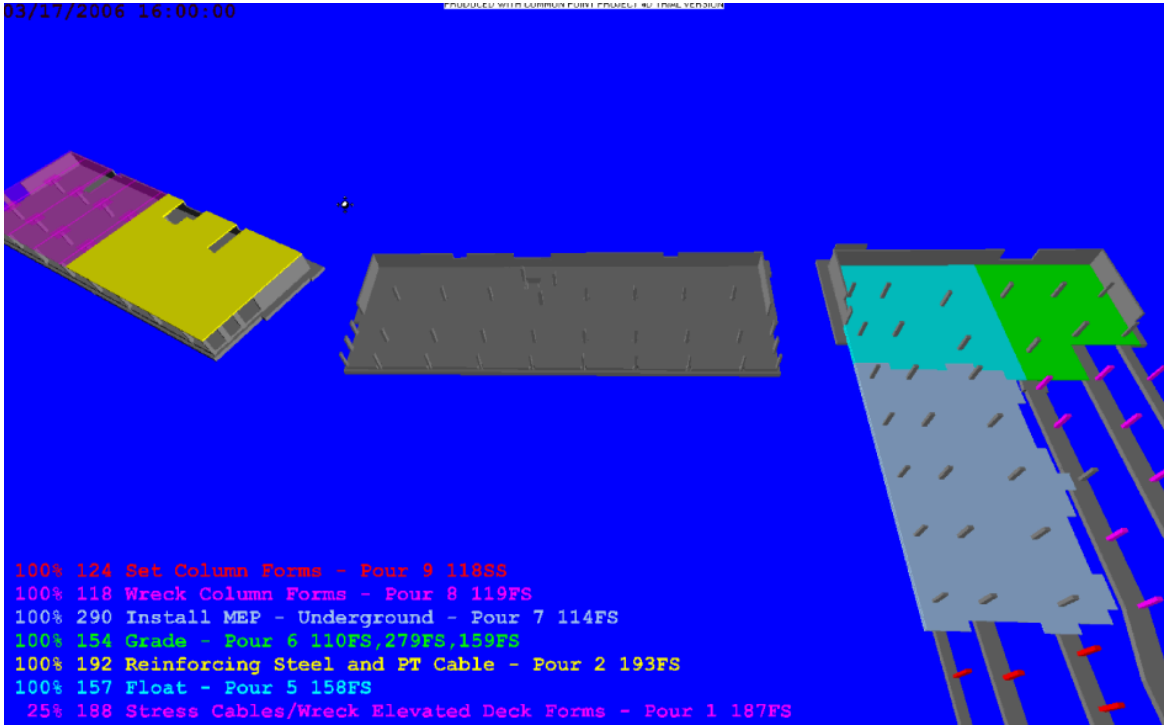
Plan the daily work of your crews and communicate work assignments to them





Courtesy Accu-Crete, Alexandria, VA

https://vimeo.com/7478891

4D modeling solves real problems

- Coordinate construction and building use and operations (1993)
- Obtain the go-ahead from the client rapidly (1993)
- Put everyone on the same page (1994)
- Coordinate fabrication and construction (1997)
- Coordinate the daily work of subs (1997)
- Find the best construction sequence (1998)
- Coordinate construction, temporary structures, and laydown areas (1998)
- Rapidly test all construction scenarios (1998)
- Assess the stability of a structure during construction (1999)
- Plan the construction of a complex project (2000)
- Communicate a complex schedule effectively to all key project participants and stakeholders (2000)
- Obtain the construction permit quickly (2000)
- Confirm access for all trades at all times (2001)
- Cut 2 months out of an already aggressive 16-month schedule (2000)
- ….

Back to the future

- Easy interfaces
- Rapid PDSA cycles
- Fabrication + construction
- Parametric 4D modeling
- Metrics about the schedule

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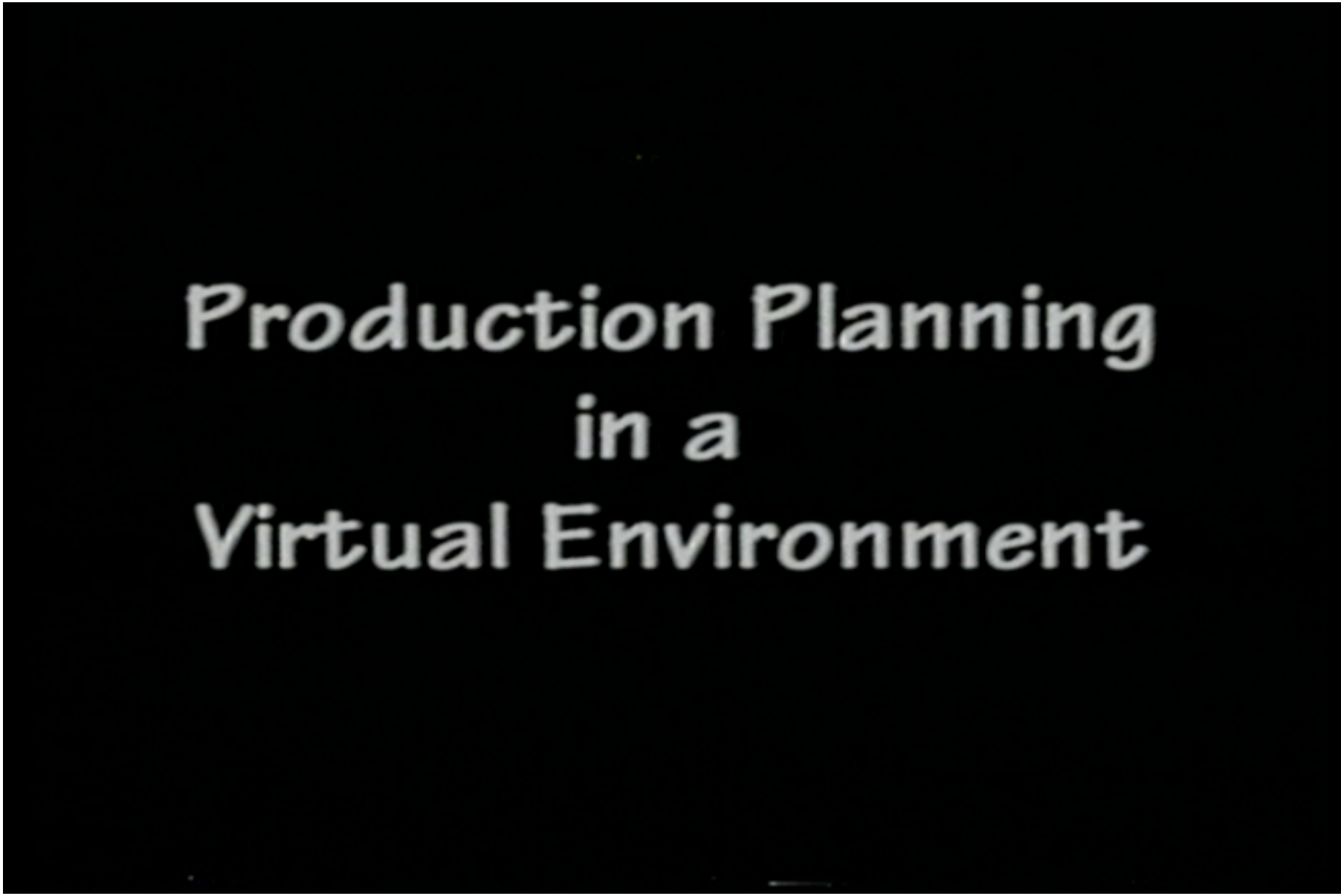

https://vimeo.com/208455958

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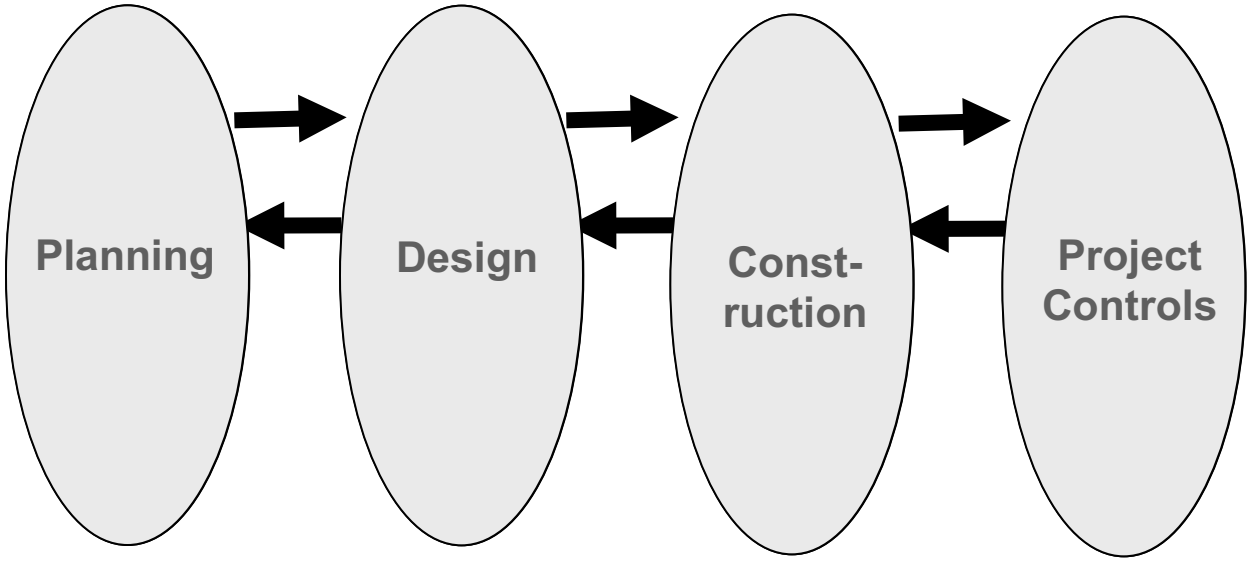
Stageworks - Objective

There is a historic "Silo Mentality" within large rail Construction projects because data is not integrated between disciplines

Software and work process integration - breaks down the barriers between the Design Silos



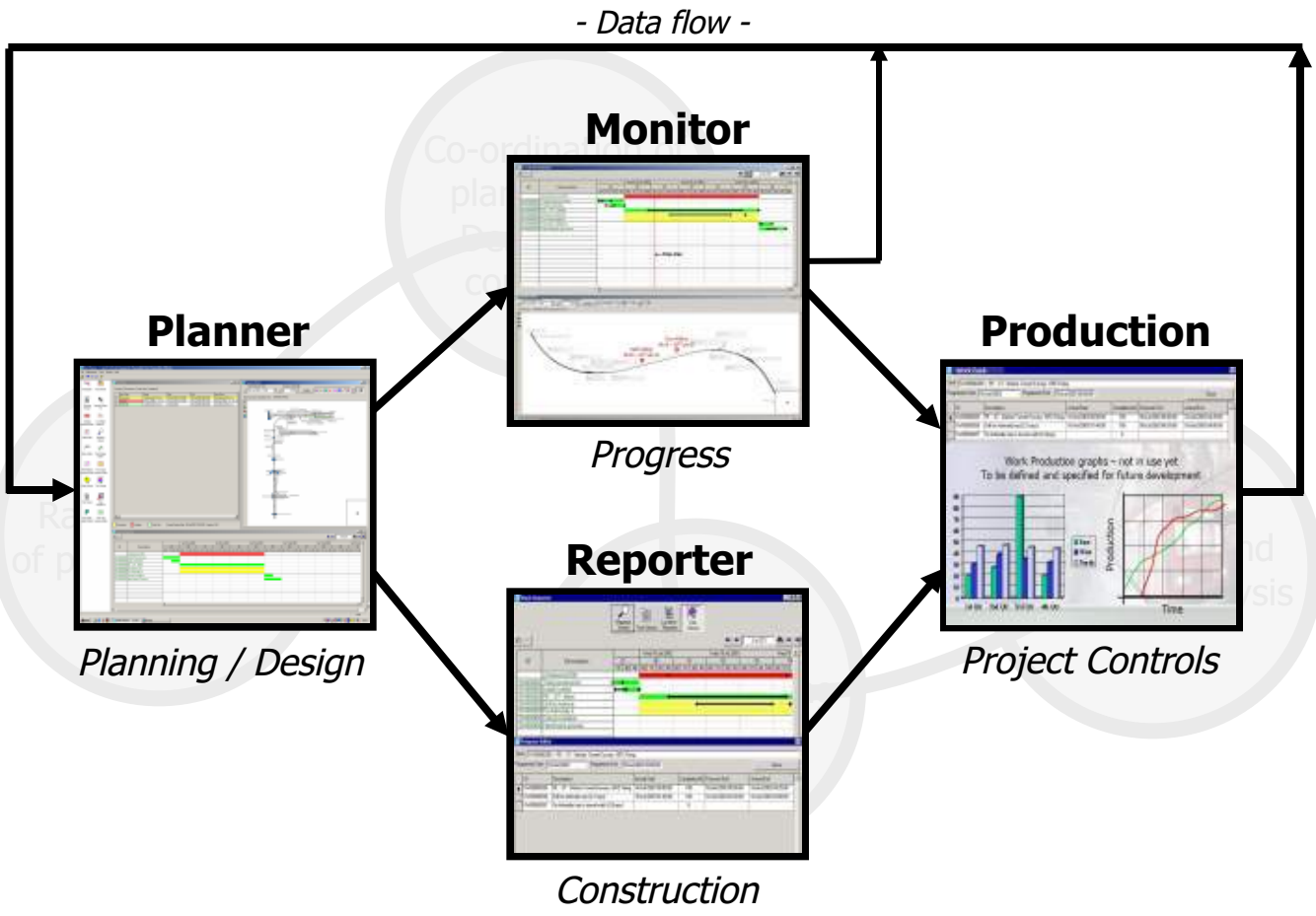
Complex Railway Standards

Multiple information formats etc

Construction of the Railway

Stageworks Application – Modules

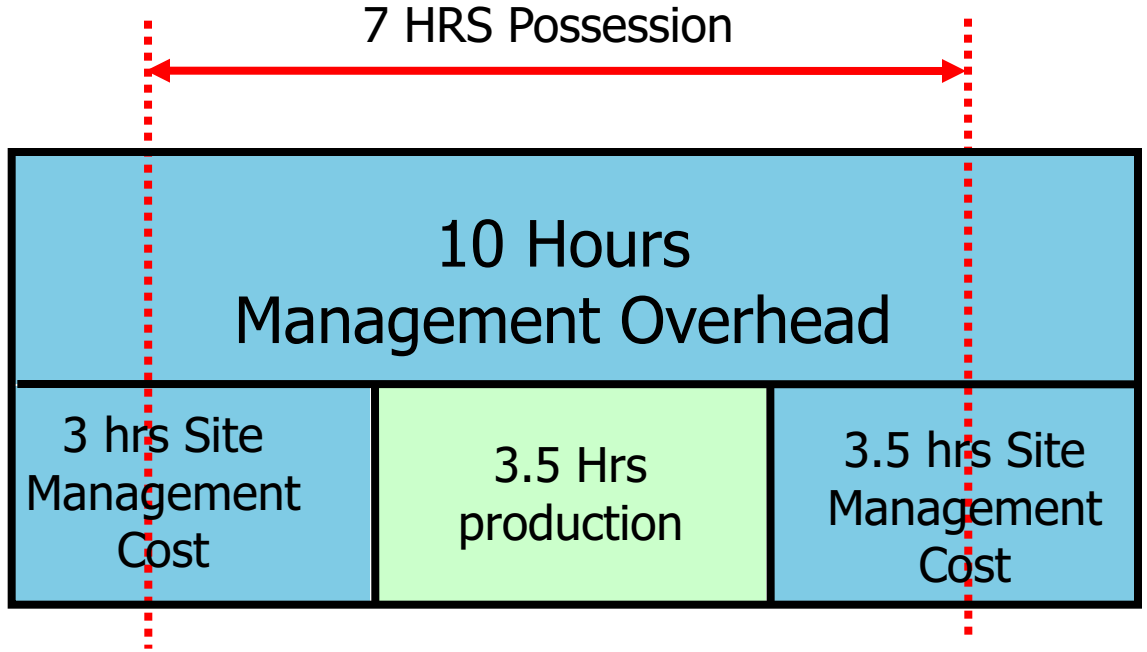
Communicating decision data throughout the life and iterations of the project



Production Data Analysis

Productivity Analysis - actual

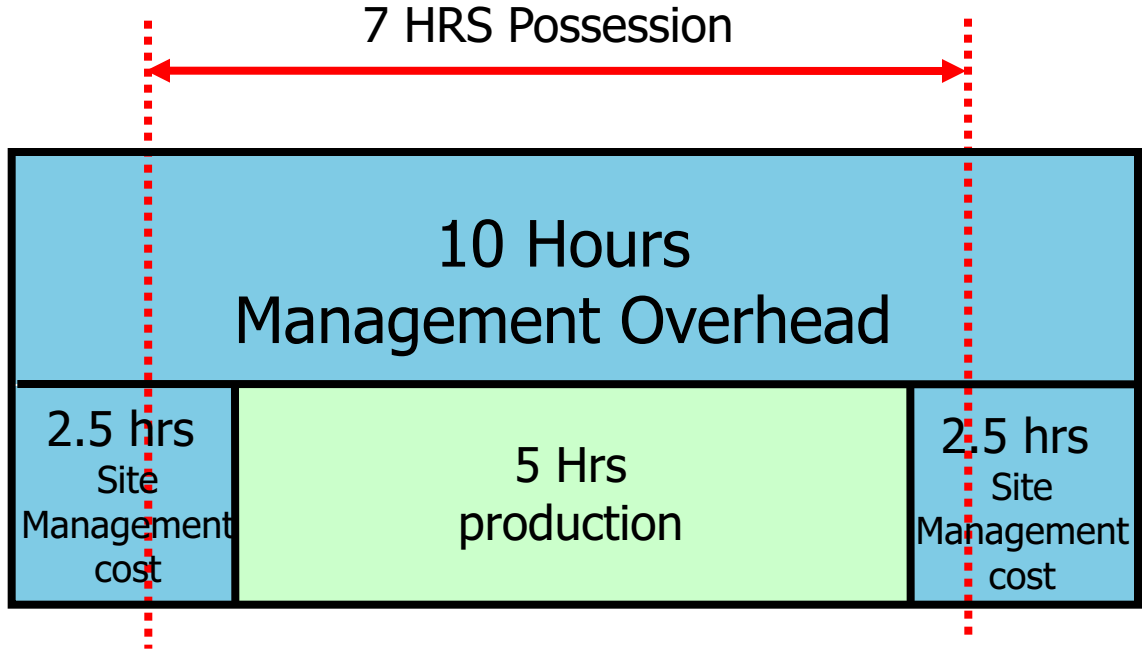
Data obtained over 30 possessions indicated 69% productive use of available worksite time.



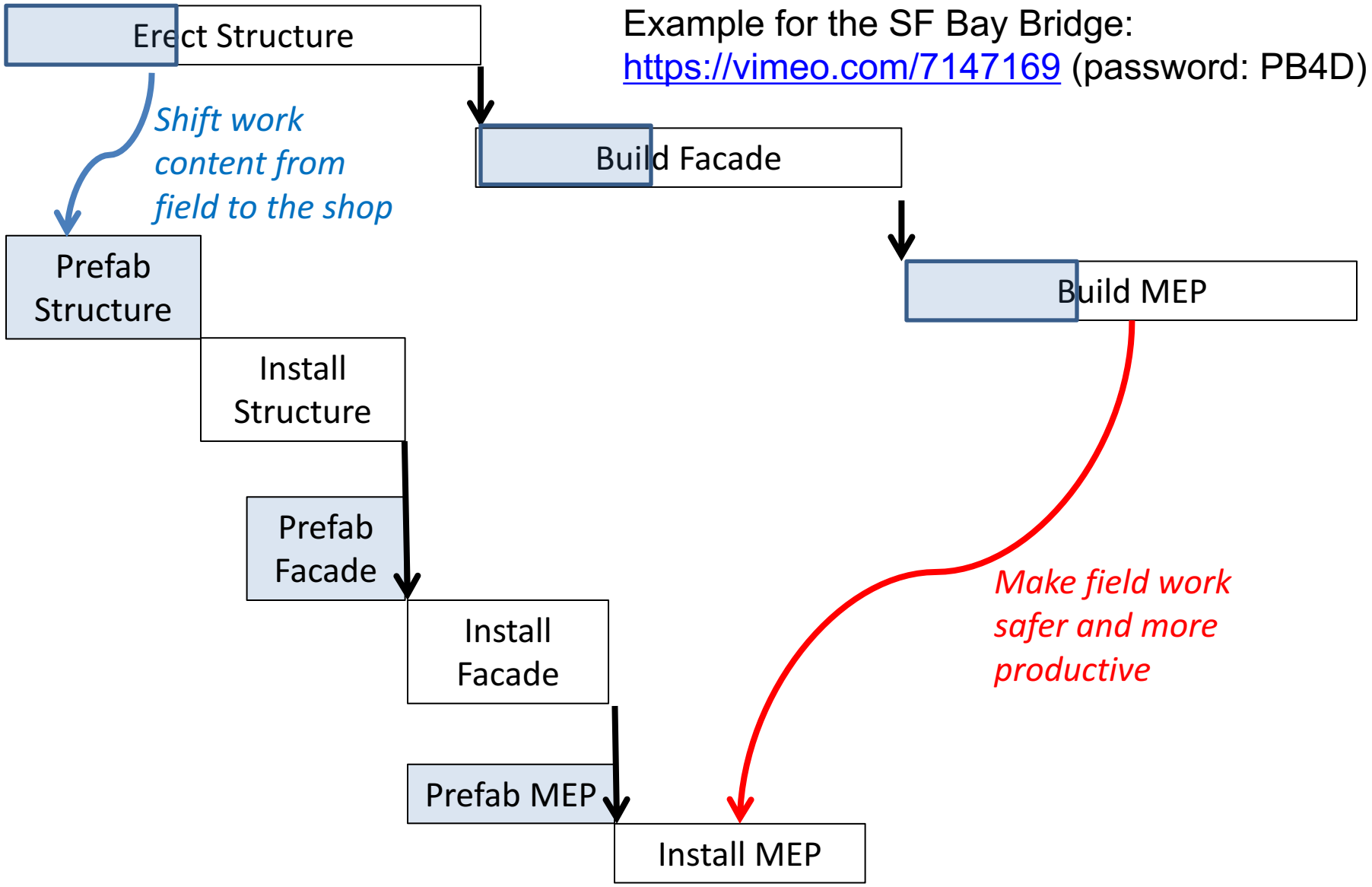
Production Data Analysis

Productivity Analysis - Improvement

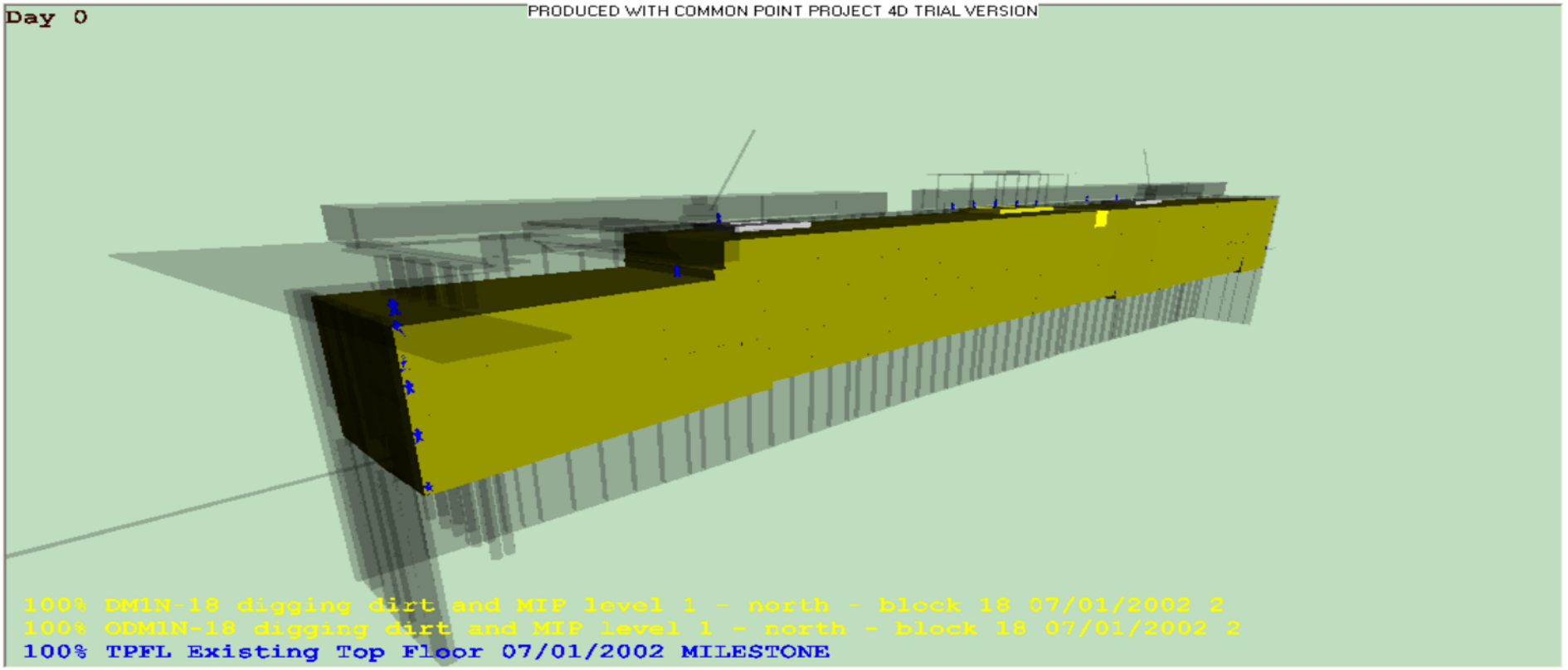
The management of these possessions delivered in the region of 95% of planned available time.



Prefabrication is the most effective approach to shorten construction schedules



Parametric 4D modeling:
Vijzelgracht Subway Station in Amsterdam



https://vimeo.com/7478855

Work with Peggy Ho and Max Boegl, Germany

https://vimeo.com/73169795

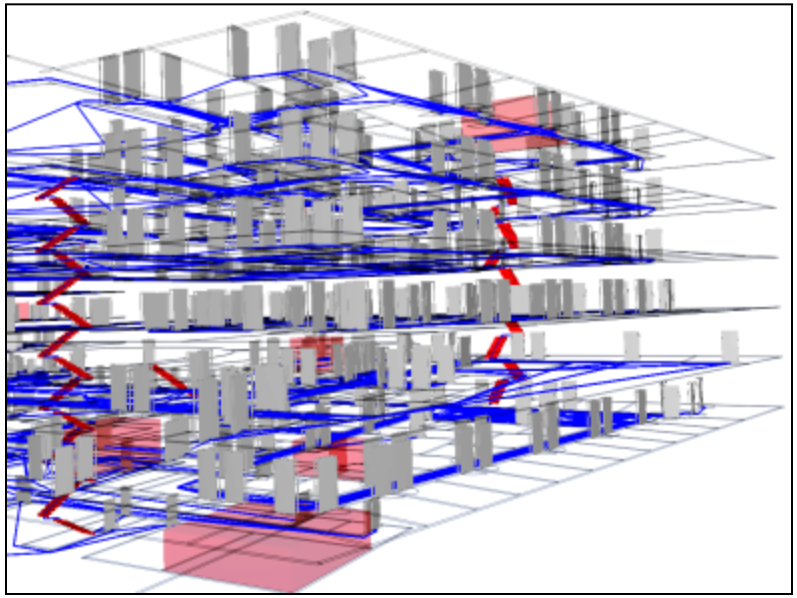
Work with Leonardo Rischmoller

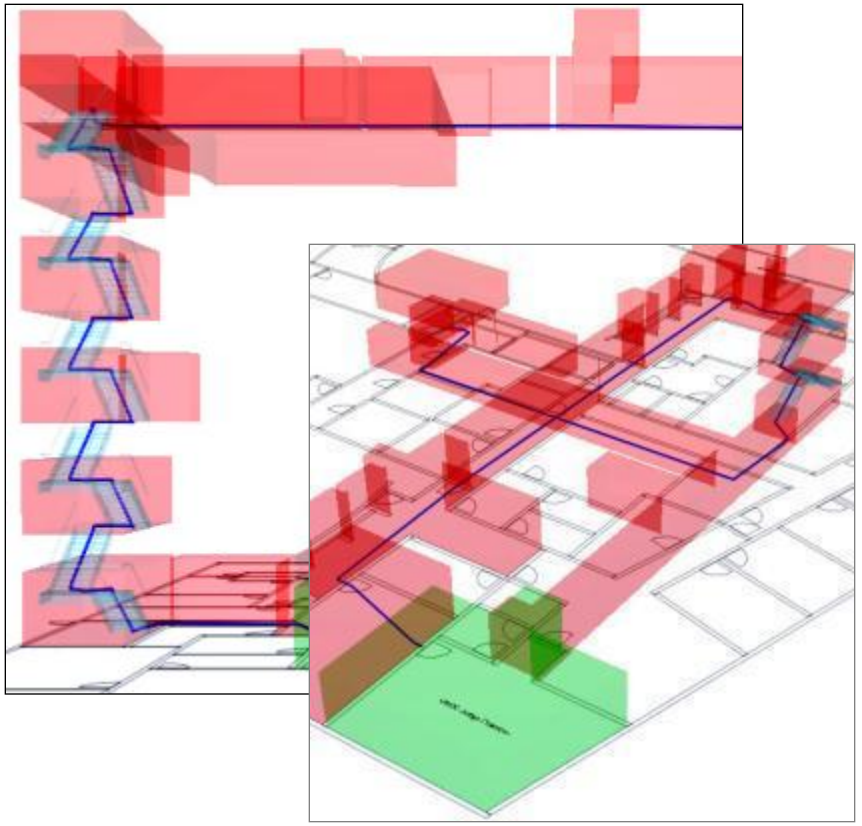
What's next?

- Beyond construction, multiple schedules
- Automated 4D modeling
- Data analytics
- Metrics about the scheduling process

Check all circulation paths in a building

On a 6-story courthouse, approximately ***27,000 routes*** were tested using ***302 circulation rules*** in approximately ***10 seconds***.

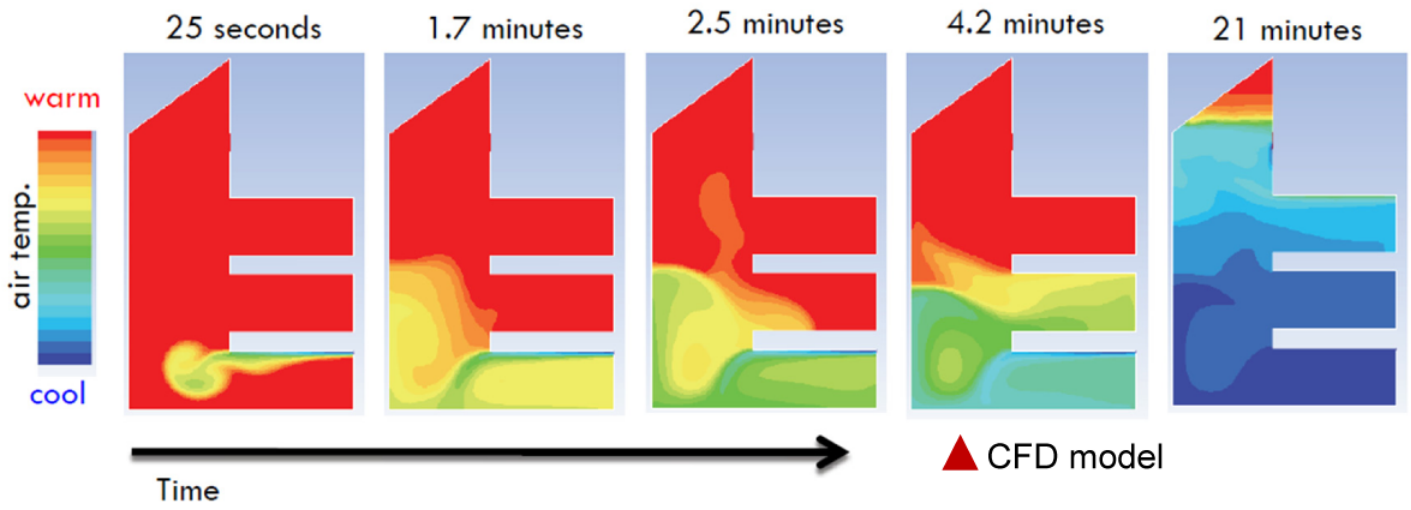


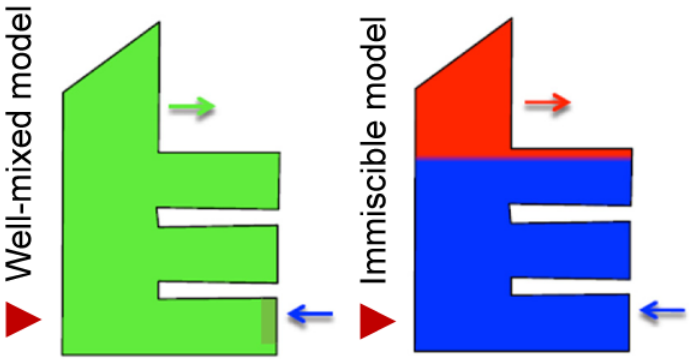


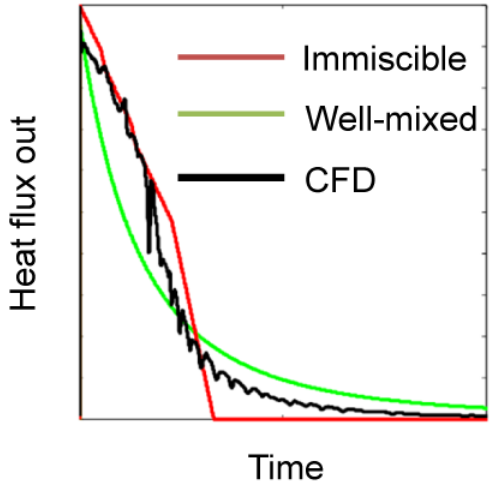
Slide courtesy GSA, work carried at GA Tech with sponsorship by the GSA

Simulation of night purge ventilation using CFD and airflow network models

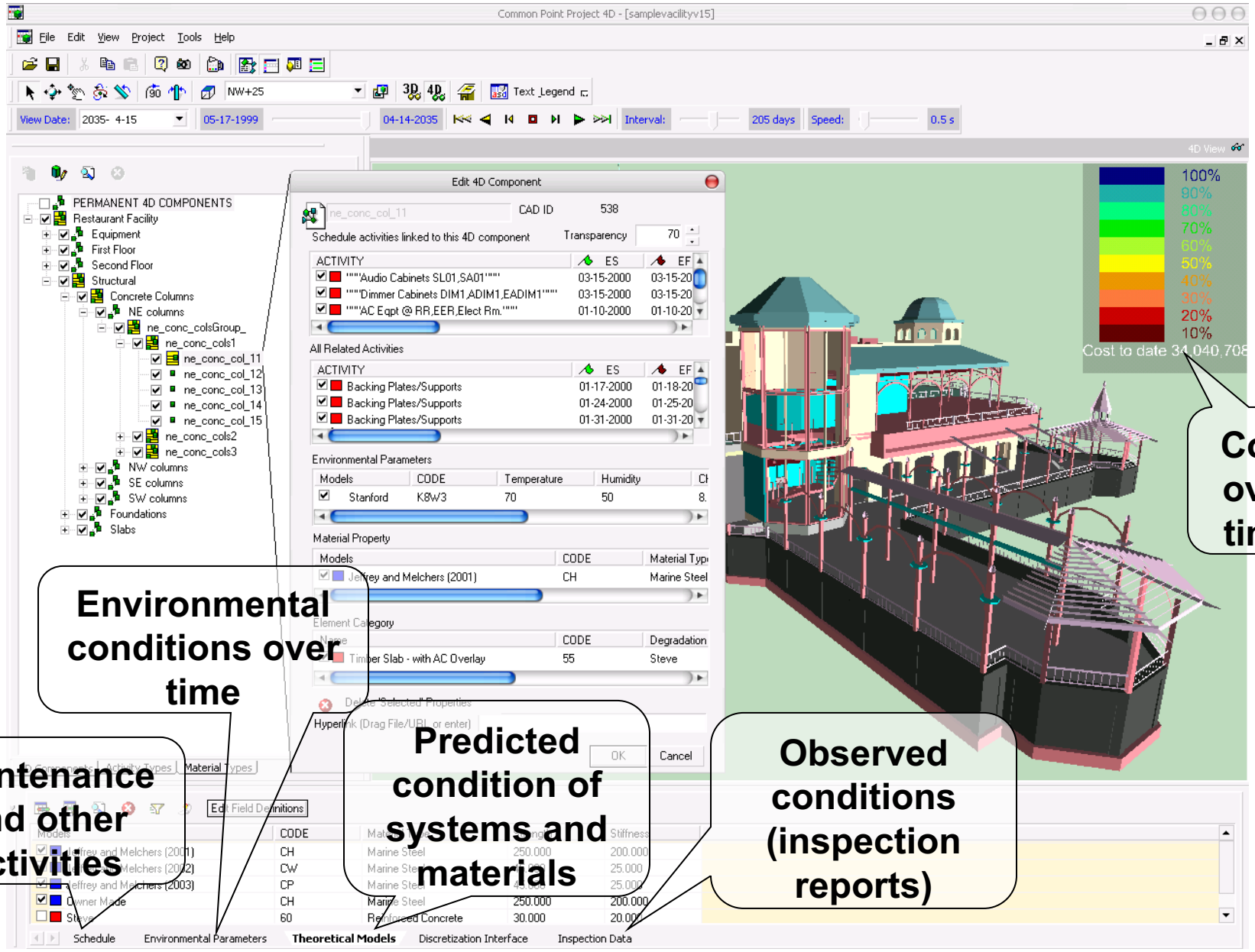
(work with Erin Hult, Gianluca Iaccarino, and Catherine Gorlé)







Facility Lifecycle Modeling in 4D



Work with Zixiao Zhang and Sarah Billington, Stanford

Accurate, timely look-ahead schedules would be helpful for complex projects in the finishing phase

- 12 types of crews
- 210 rooms per floor
- 20 operations per room on average

- Precedence constraints
- Crew availability
- Room availability and priority
- Blocking constraints
- Zone constraints

Carnegie Mellon University (CMU) campus project in Doha, Qatar
Collaboration with CCC

Content of a LAS for the finishing phase

05/05/08 → 05/19/08 → 07/10/08 → 07/17/08 → 07/31/08 → 08/14/08 → 08/21/08

Work Calendar

	1/2/2009	1/5/2009	1/6/2009	1/7/2009	1/8/2009	1/9/2009	1/12/2009	1/13/2009
COR1	[E001]; [Conduit and Box]	[E001]; [Conduit and Box]	[C001]; [Dry Wall]	[C001]; [Dry Wall]	[C001]; [Dry Wall]	[C001]; [Dry Wall]	[C001]; [Dry Wall]	[C001]; [Dr
ELE1								
ELE2	[D9001]; [Plastering]	[D9001]; [Plastering]	[D9001]; [Plastering]	[D9001]; [Plastering]	[C10001]; [Screed]	[P001]; [Painting (Two Coats)]	[P001]; [Painting (Two Coats)]	[P001]; [Pa Coats)]
IDF1					[D9001]; [Plastering]	[D9001]; [Plastering]	[D9001]; [Plastering]	[D9001]; [F
IDF2								
PLT1	[D9002]; [Plastering]	[D9002]; [Plastering]	[D9002]; [Plastering]	[D9002]; [Plastering]	[D9002]; [Plastering]	[D9002]; [Plastering]	[D9002]; [Plastering]	[D9002]; [F

Room ID

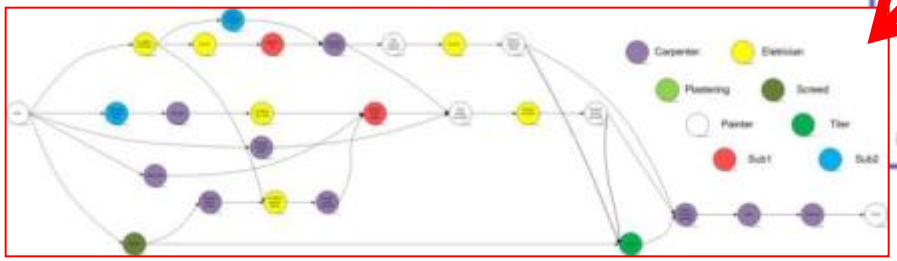
	1/2/2009	1/5/2009 ← When
Where → COR1	[E001]; [Conduit and Box]	[E001]; [Conduit and Box]

Who What

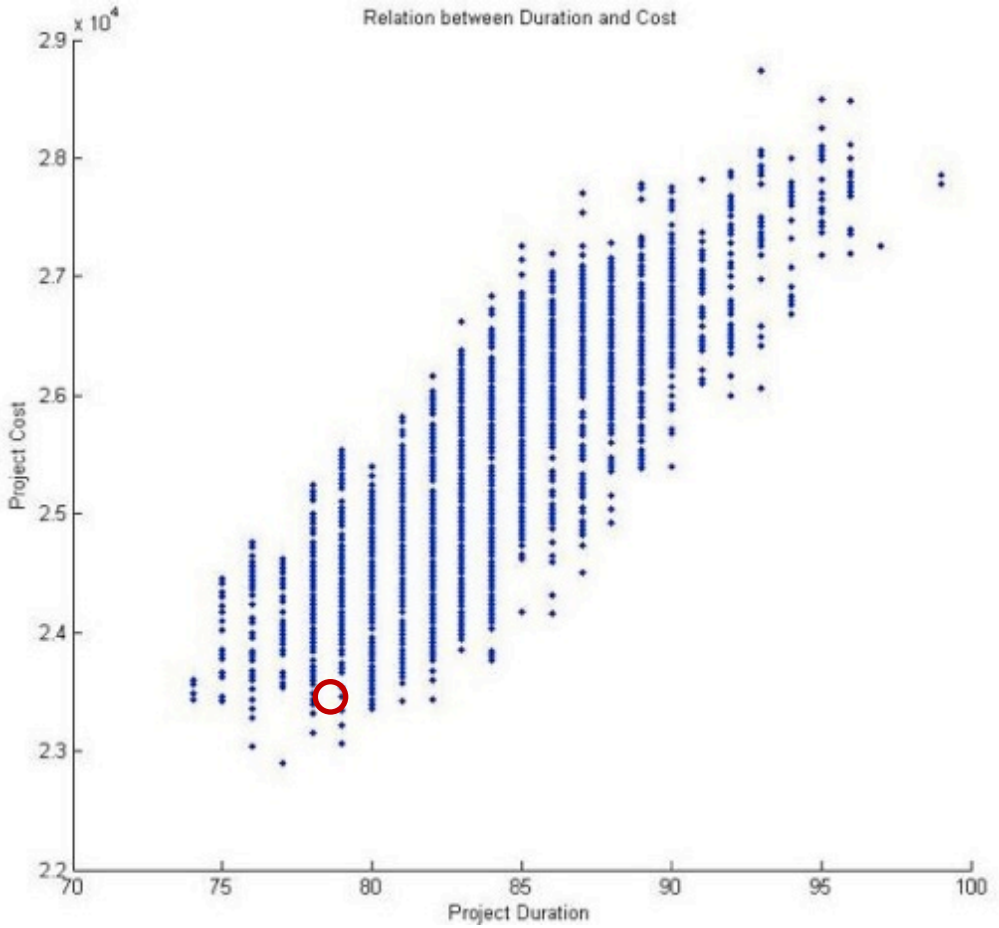
Formalizing the finishing work with fragnets

- 50+ Crews
- Hundreds of activities
- 200+ rooms

Who will do what when where?

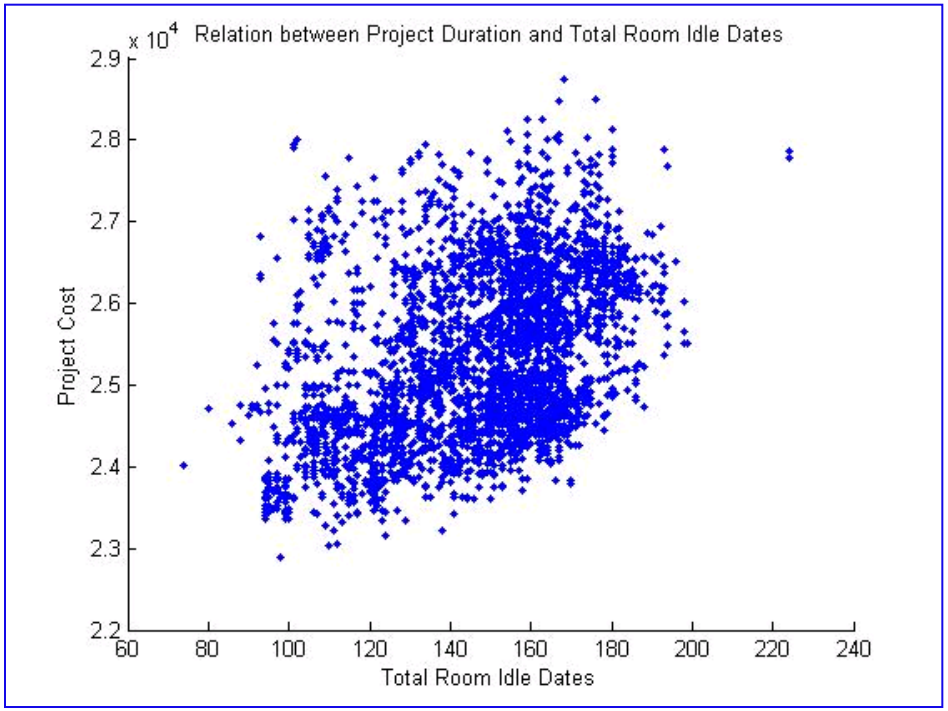


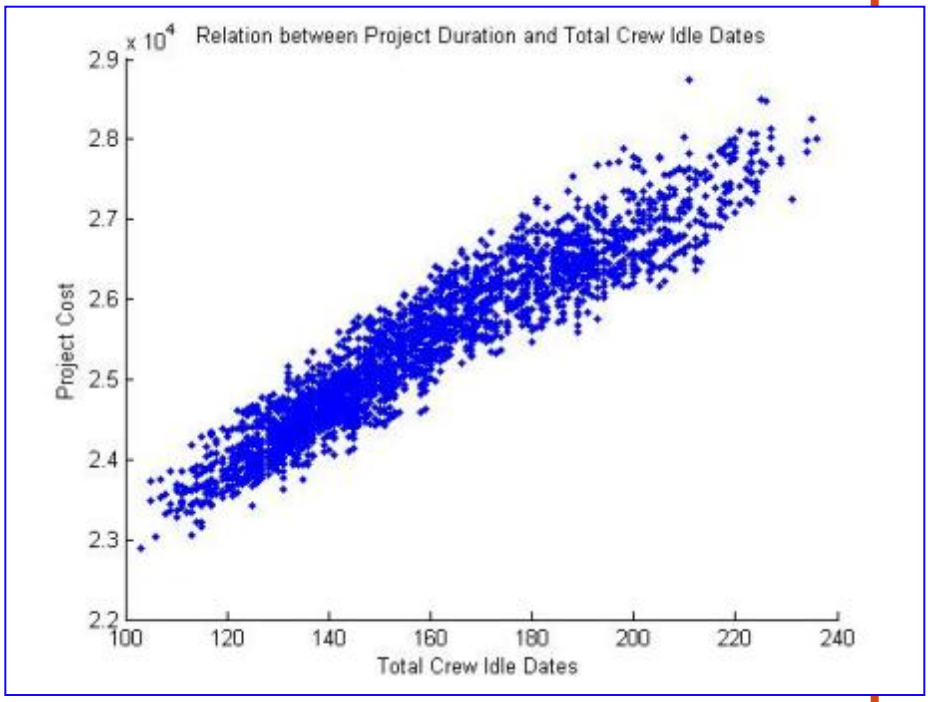
With automated scheduling the optimal resource allocation can be determined



The schedule with the shortest duration is not the schedule with the lowest cost.

Testing Construction Management Heuristics

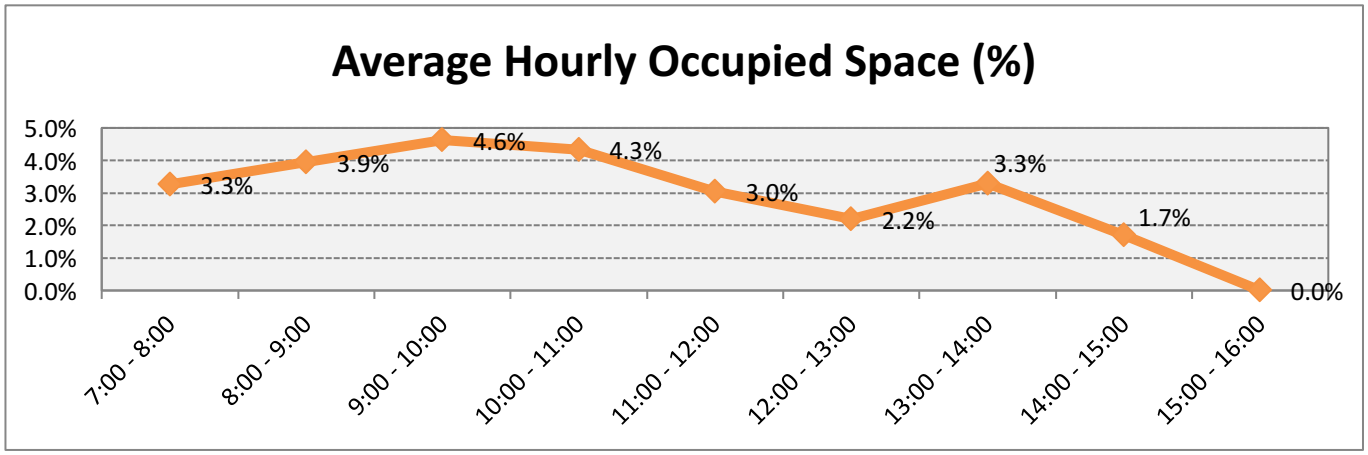




Working in **as many locations as possible** does not lead to a schedule with minimum cost.

Making **crews as busy as possible** leads to the schedule with minimum cost.

Space is underutilized on some construction sites



Average bay occupancy 3.1%

Need a method to maximize work density

Work with René Morkos

Flow-based Construction Site Management

Nelly Garcia-Lopez

In Collaboration with
Graña y Montero (Lima)
Grupo Galopa (Bogota)
MT Højgaard (Copenhagen)

Case study: Applying the flow-based site management method

Project info:

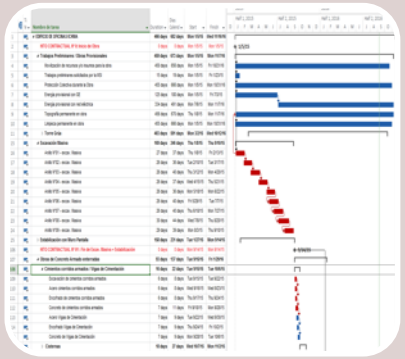
- Graña y Montero jobsite in Peru
- 11 basements + 21 floors
- 18-week period (8 weeks on site)
- Structural phase

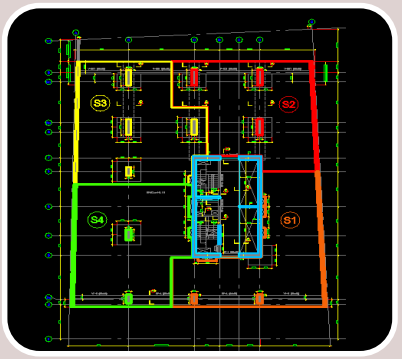
Objectives:

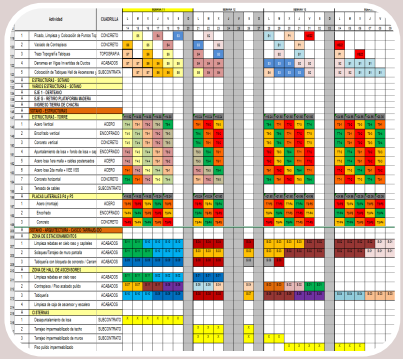
1. Can the flow-based model represent the look-ahead plan?

2. Does the method help field managers make decisions during look-ahead and daily planning?

Case study project used best practices for production planning







Master plan

- Processes
- Gross constraints

Takt plan

- Sector definition
- Quantities
- Trade sequence
- Crew balancing

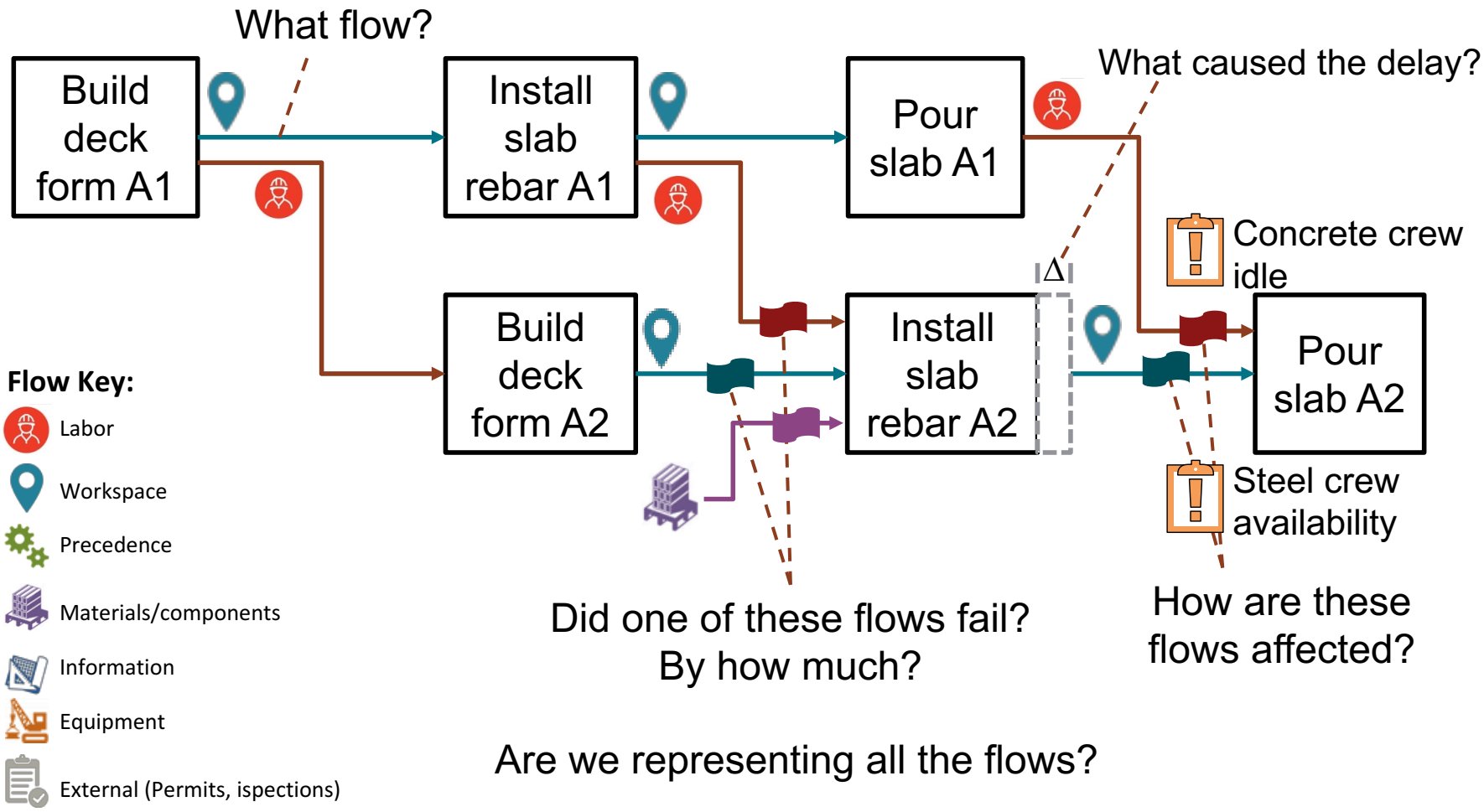
Look-ahead plan

- Constraints analysis
- Productivity
- PPC + reasons

Daily plan

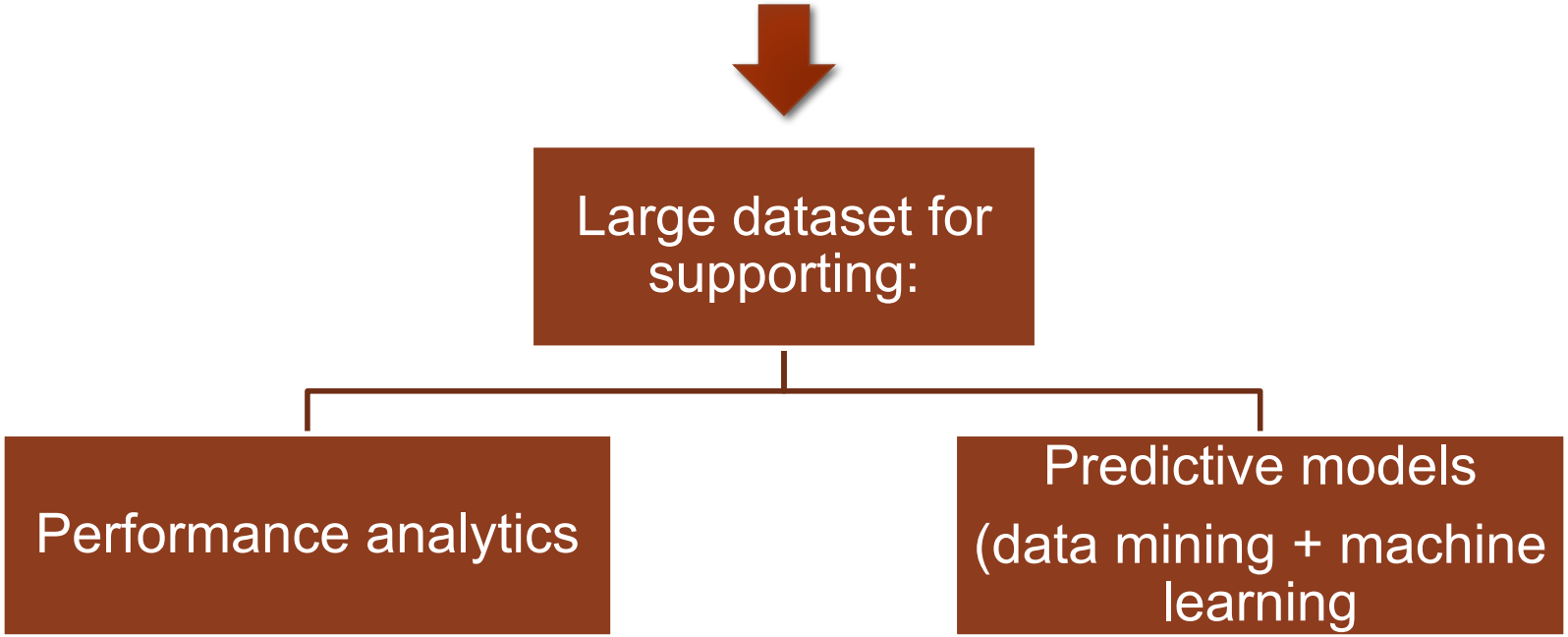
- Quantities
- Productivity
- Daily PPC
- Visual planning

Existing construction models do not formally represent, track, or quantify the activity flows

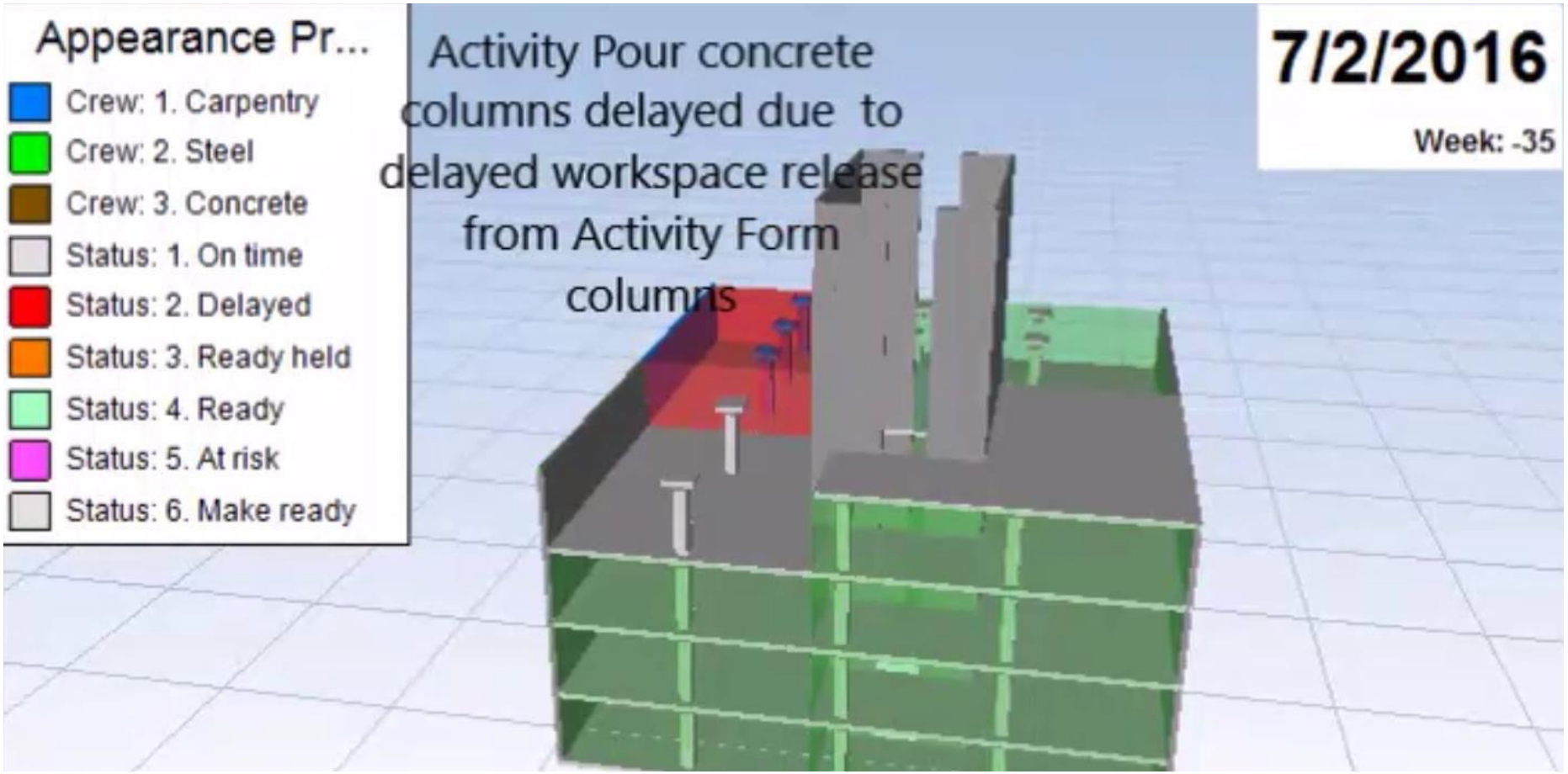


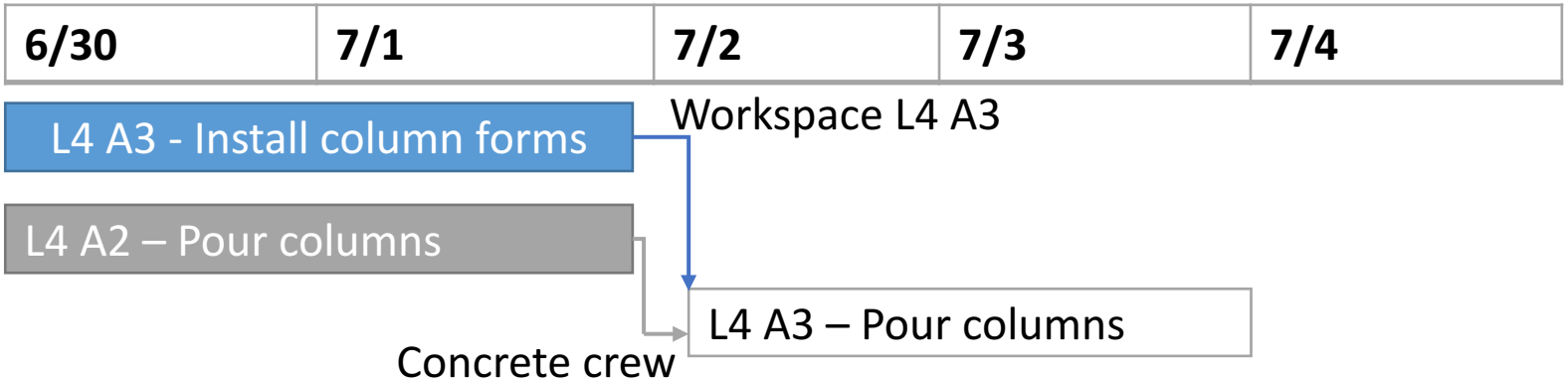
GyM case study data (18 weeks)

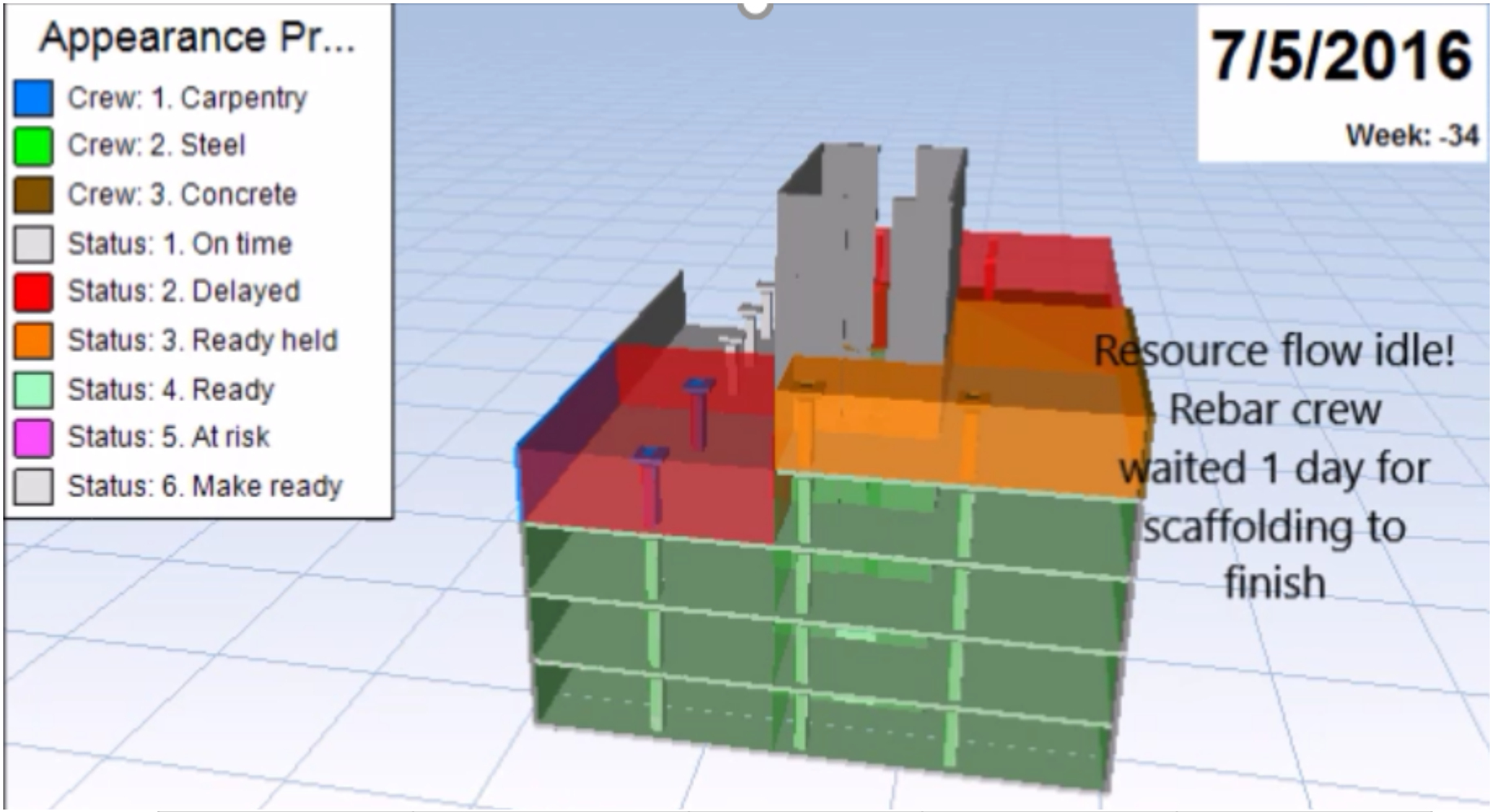
	Total	Per week
# Activities	1,153	64
# Flows	4,192	232
# Data points	**415,008**	**23,056**

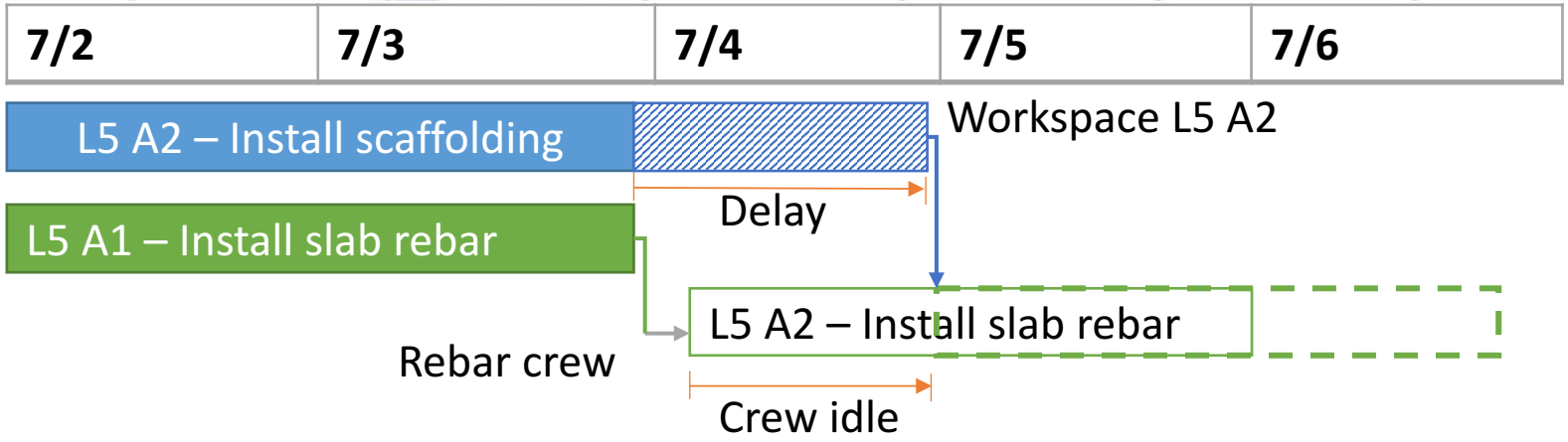


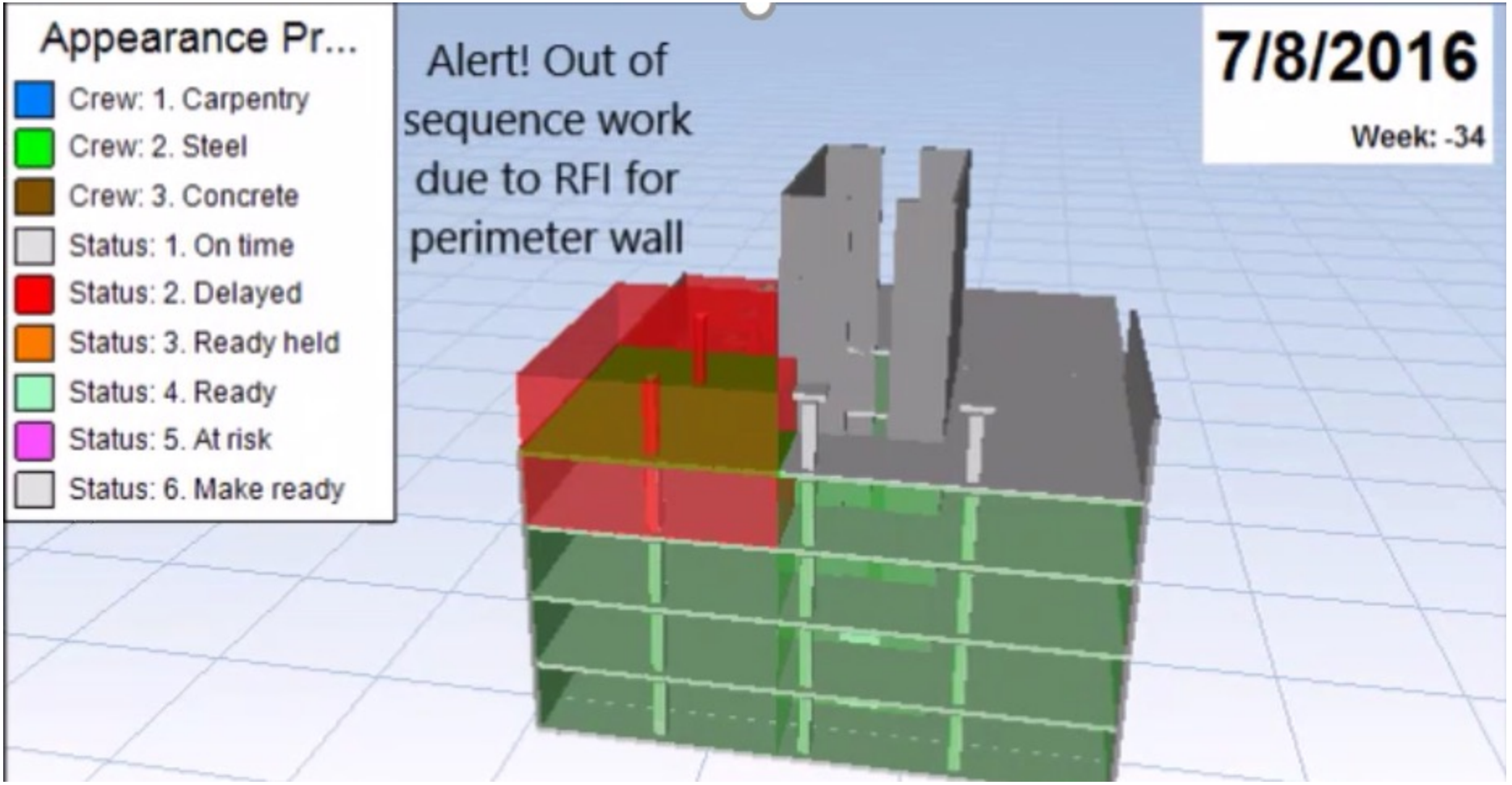
Total additional data collection effort: 45 hours


Appearance Pr...
Crew: 1. Carpentry
Crew: 2. Steel
Crew: 3. Concrete
Status: 1. On time
Status: 2. Delayed
Status: 3. Ready held
Status: 4. Ready
Status: 5. At risk
Status: 6. Make ready
Activity Pour concrete columns delayed due to delayed workspace release from Activity Form columns
7/2/2016
Week: -35


6/30
7/1
7/2
7/3
7/4
Workspace L4 A3
L4 A3 - Install column forms
L4 A2 – Pour columns
L4 A3 – Pour columns
Concrete crew


Appearance Pr...
Crew: 1. Carpentry
Crew: 2. Steel
Crew: 3. Concrete
Status: 1. On time
Status: 2. Delayed
Status: 3. Ready held
Status: 4. Ready
Status: 5. At risk
Status: 6. Make ready
7/5/2016
Week: -34
Resource flow idle!
Rebar crew
waited 1 day for
scaffolding to
finish


7/2
7/3
7/4
7/5
7/6
L5 A2 – Install scaffolding
Workspace L5 A2
Delay
L5 A1 – Install slab rebar
L5 A2 – Install slab rebar
Rebar crew
Crew idle



7/8	7/9	7/10	7/11

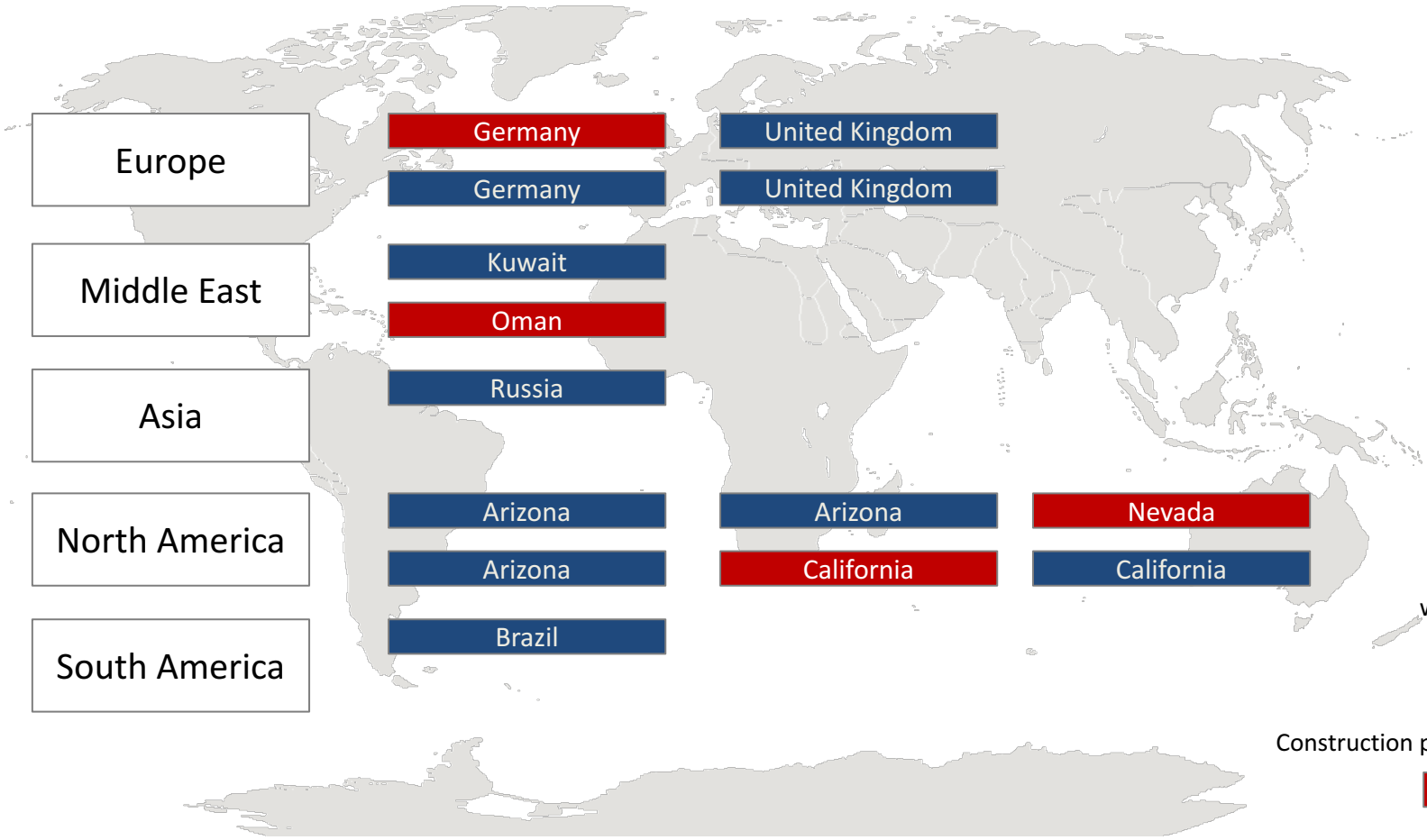
RFI
Due date: 7/7
OVERDUE!

L5 A3 – Install wall rebar

Rebar crew

L5 A4 – Install wall rebar

14 projects studied



Large projects

100 – 700 M USD

Project types

Residential

Commercial

Educational

Industrial

Role models

Best practice examples within their organizations

Construction planning largely based on

BIM

Lean

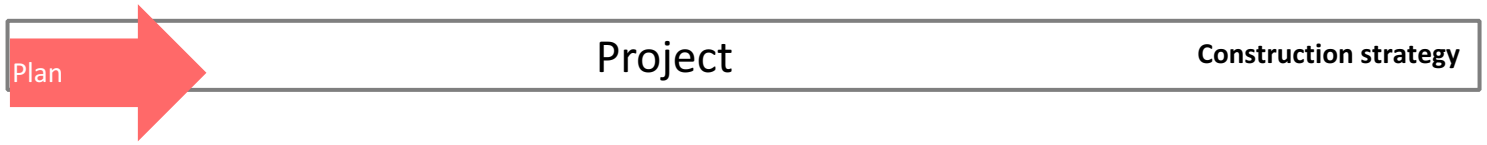
Work with Maximilian Schütz, CIFE & Max Bögl, with support from Autodesk

We have data from all 14 projects, we visited 9 projects in person at least once.

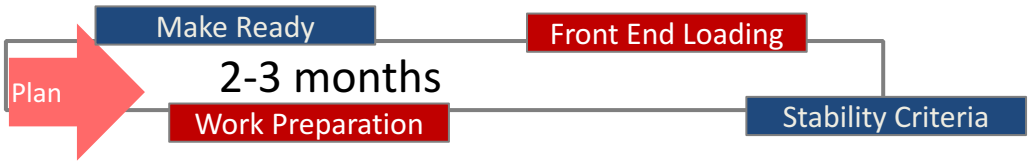
4 Planning cycles observed

 # Projects

14



14



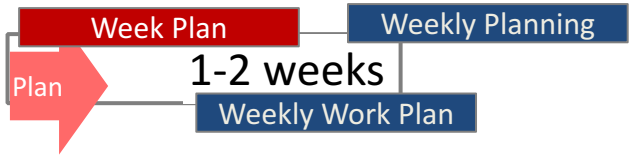
Supply Chain Management

Design documents

Resources and material

Logistics

14

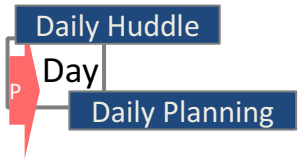


Production Planning

Final sequencing

Collaborative Commitment

6



Final Decision

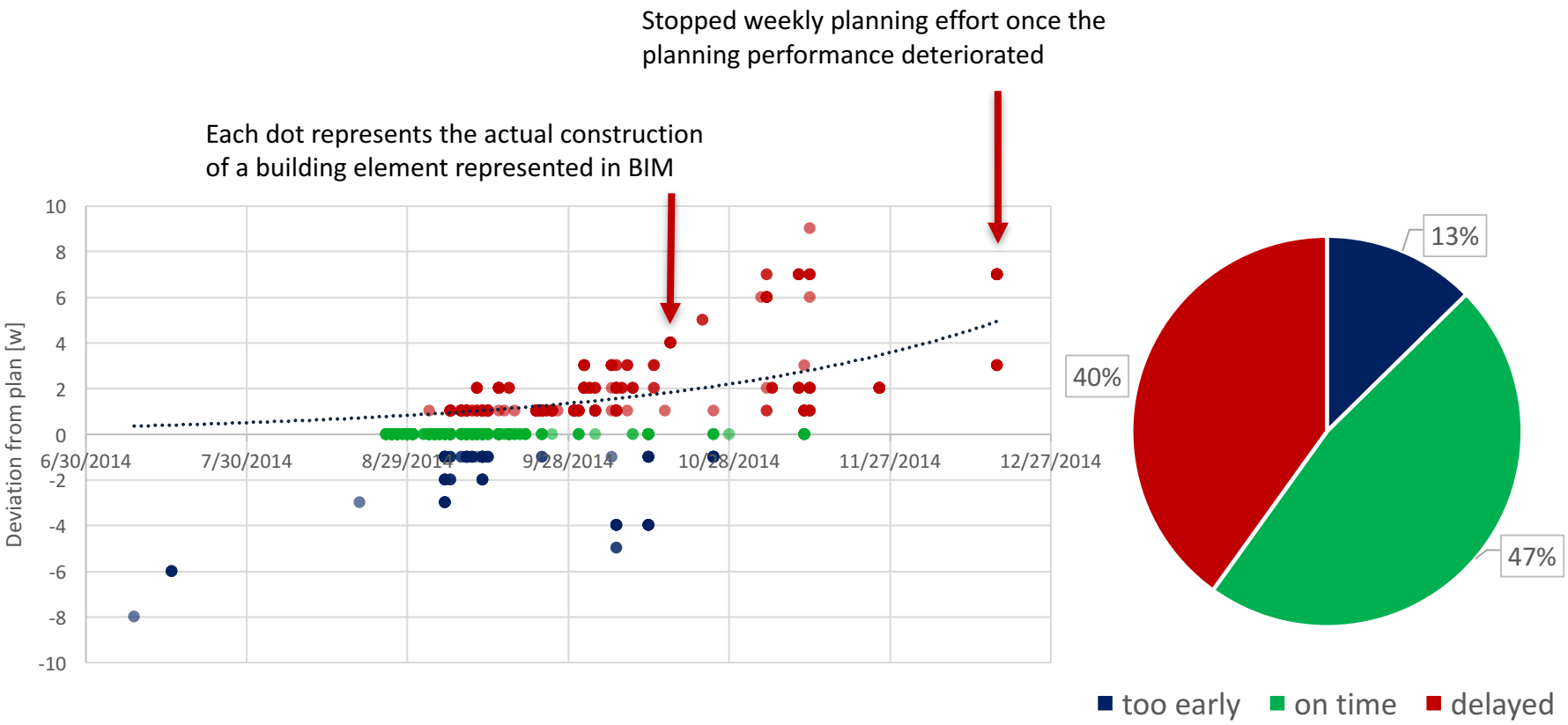
Last Check-in

Status of completion

Terminology of projects

BIM Lean

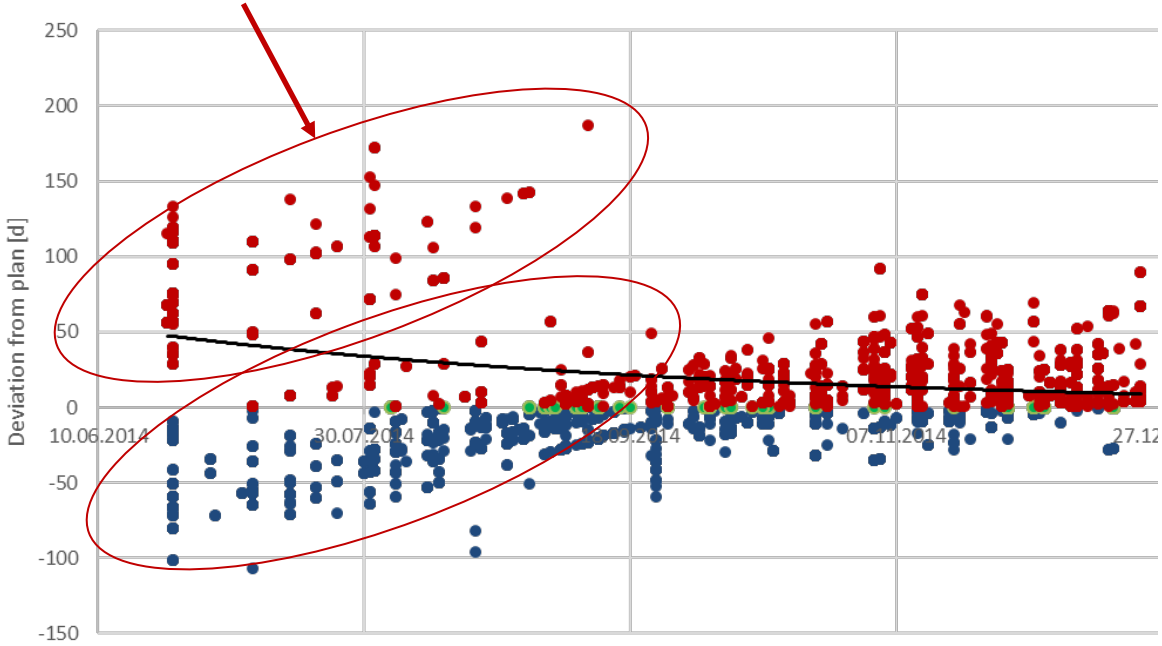
Planning accuracy of weekly work plans

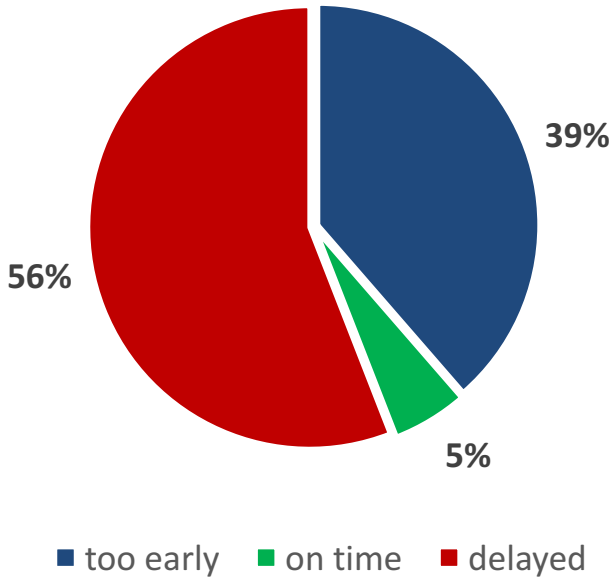


Project in Germany N = 918 BIM elements

Planning accuracy of 2-month look-ahead plans

Major changes in sequence



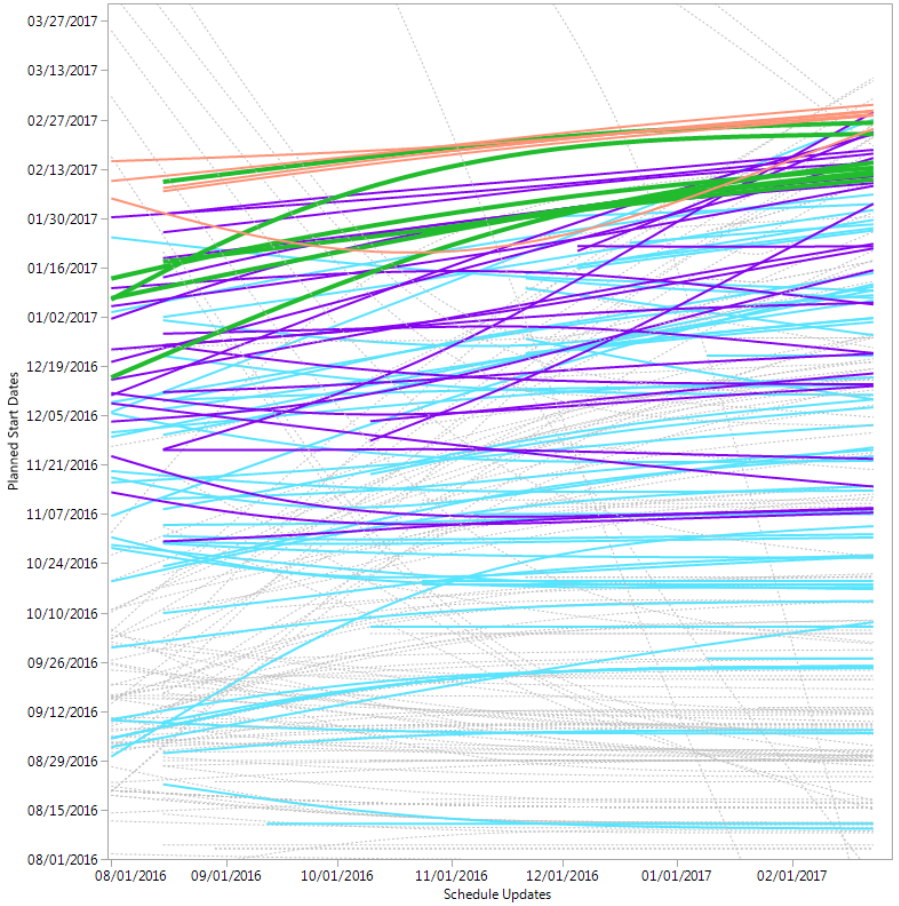


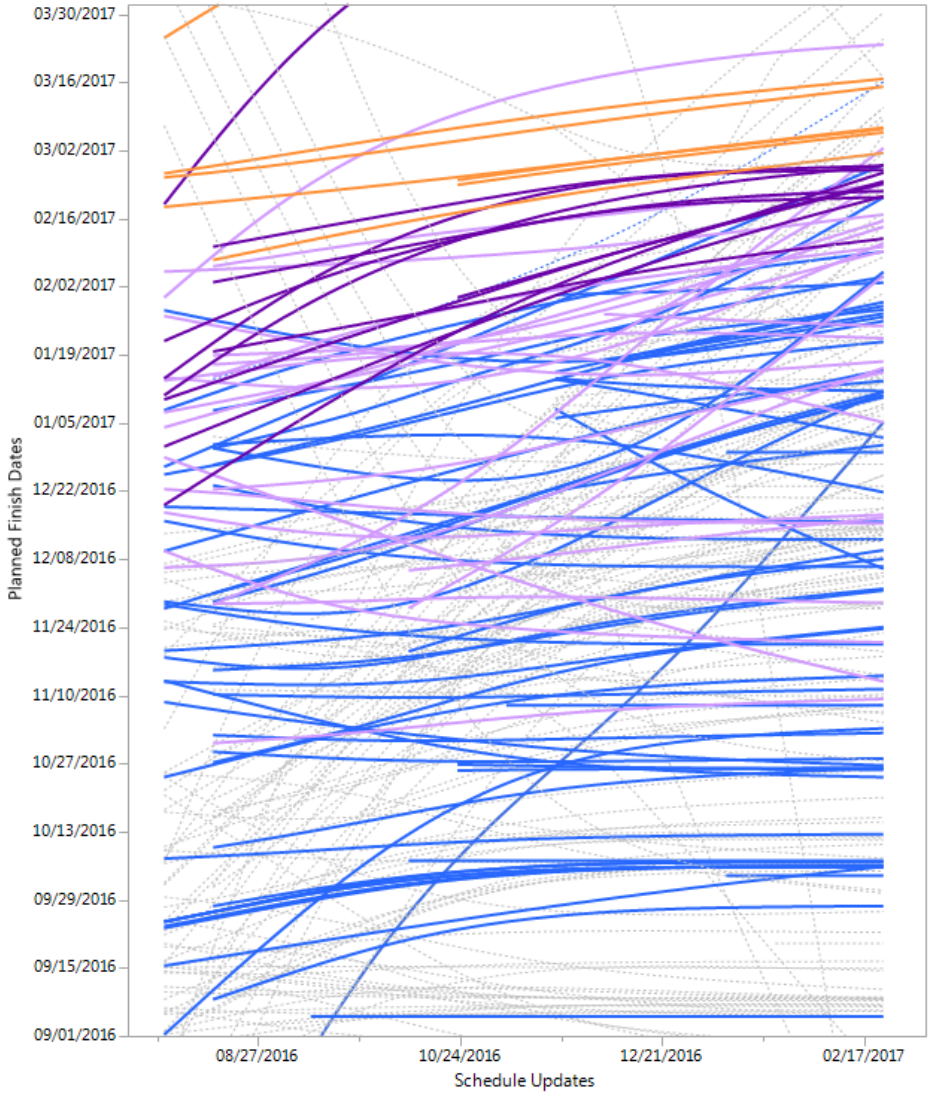
2-month look-ahead plans were 5% accurate

Project in Germany N = 5914 BIM elements Mean delay: 31 d

Stability of schedules over time

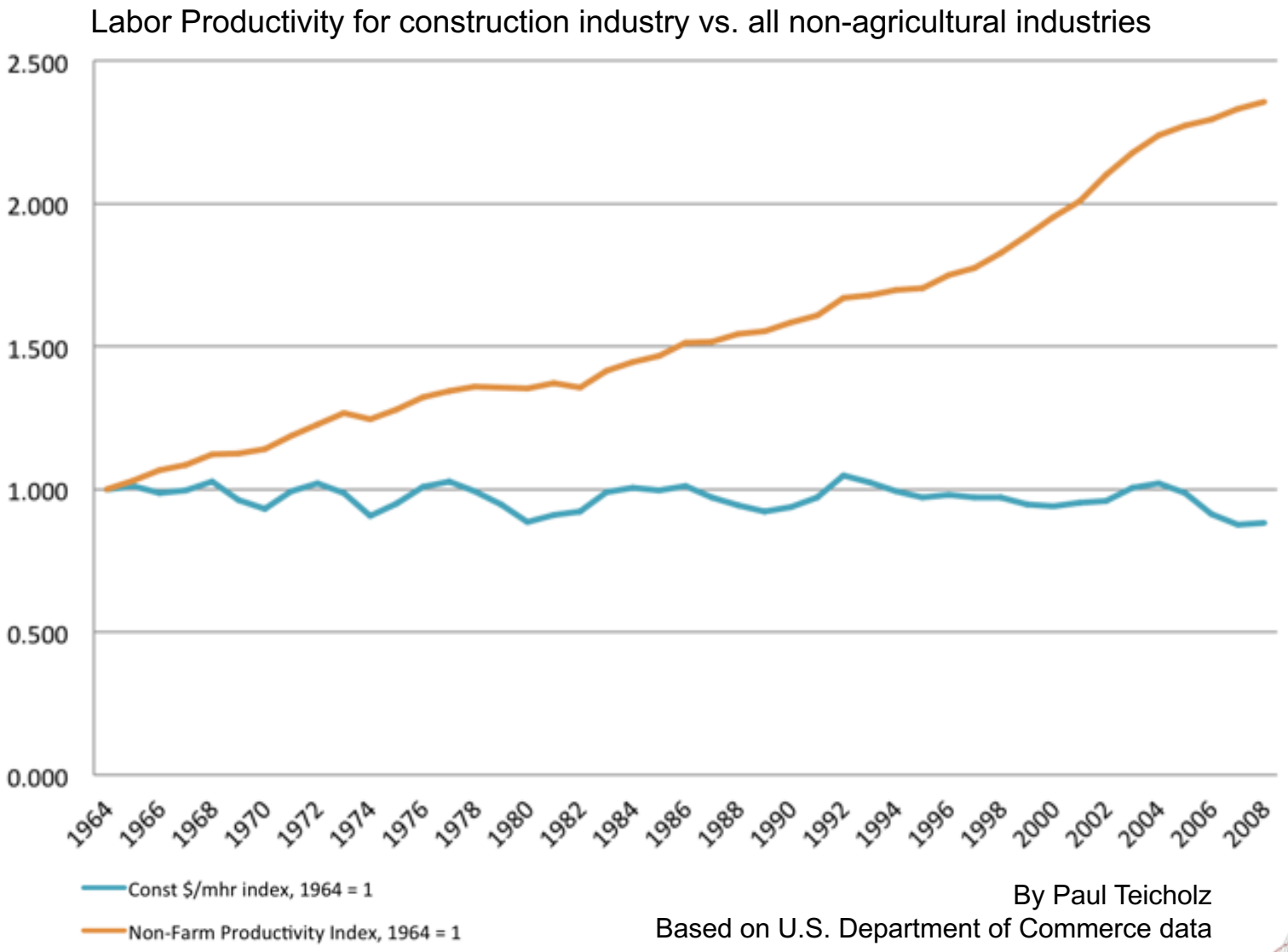
Diagrams show changes in activity start dates (y-axis) from schedule update to schedule update (x axis). An activity is represented by a line. The left diagram shows a relatively stable schedule (many lines are horizontal or close to horizontal). The right diagram shows a chaotic schedule (many activities have significant changes in start date).





Work with Parisa Nikhoo, DPR

Productivity in construction lags productivity in other industries



By Paul Teicholz
Based on U.S. Department of Commerce data

CIFE

Vision –
A future I would like to make happen

Every workhour builds the right product safely and productively

Definition of Vision by Robert Burgelman, GSB, Stanford

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